N92-30264

NATIONAL EDUCATORS' WORKSHOP
NEW: Update 91

STRUCTURAL CERAMICS

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Oak Ridge National Laboratory

November 12-14, 1991

PERSPECTIVES ON WHERE MATERIALS ARE GOING

MATERIALS SCIENCE AND ENGINEERING FOR THE 1990s, MAINTAINING COMPETITIVENESS IN THE AGE OF MATERIALS, National Research Council, National Academy Press, Washington D.C. 1989

M. F. Ashby, "TECHNOLOGY OF THE 1990s: ADVANCED MATERIALS AND PREDICTIVE DESIGN", Phil. Trans. R. Soc. Lond. A 322, 393-407 (1987)

E. L. Langer, "EVOLUTION OF ADVANCED MATERIALS IN A CHANGING WORLD", International Conference on Evolution of Advanced Materials, AIM/ASM, Milano Italy, May 31-June 2, 1989

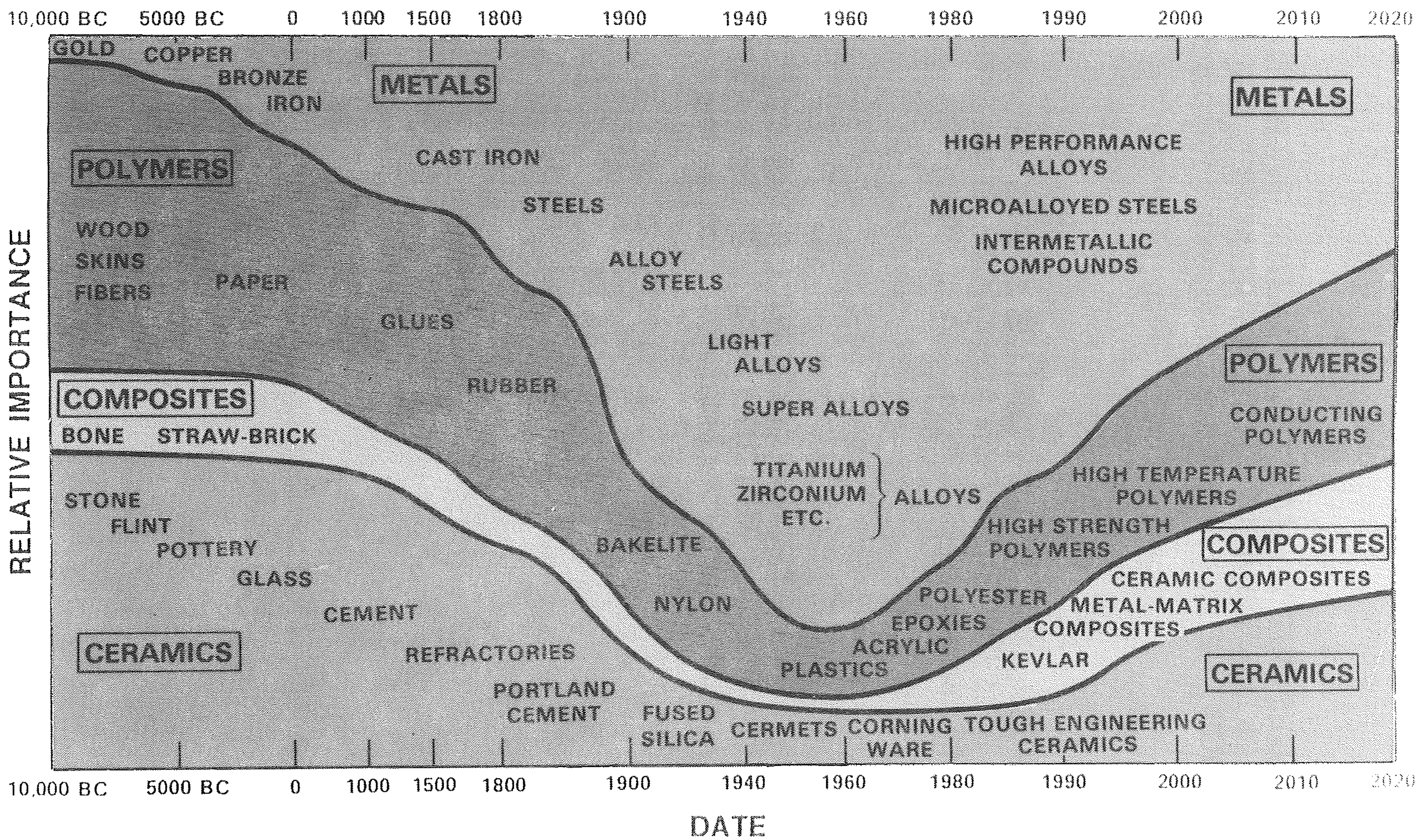
IMPACT OF MATERIALS

IN 1982, DAMAGES DUE TO MATERIAL FAILURE WERE GREATER THAN $200 BILLION ANNUALLY - THIS APPROACHES THE ANNUAL FEDERAL DEFICIT. (M. Cohen in Advanced Materials Research, NAS/NAE, 1987)

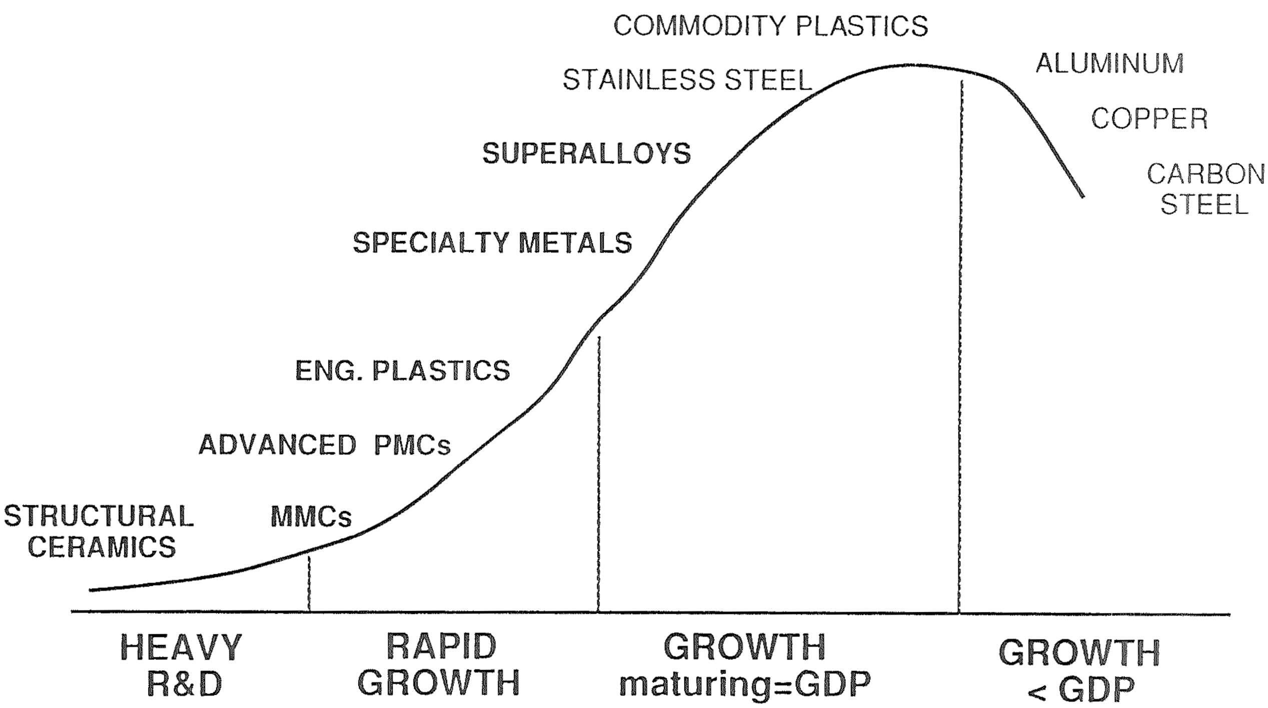
COMPETITIVENESS AND QUALITY OF LIFE IN THIS DECADE AND 21st CENTURY WILL DEPEND UPON ADVANCES IN MATERIALS. (paraphrase of R. Chianelli, MRS Bulletin, August, 1990)

LEADERS IN MATERIALS TECHNOLOGY WILL DOMINATE THE MARKETPLACE IN THE 21st CENTURY. (Panel discussion at Int'l Symp. Basic Technologies for Future Industries, Kobe, Japan, March 1989)

EVOLUTION OF MATERIALS SCIENCE AND ENGINEERING



COMMODITY METALS AND PLASTICS HAVE PASSED DEMAND PEAK AND USAGE IS DECLINING



THERE IS A CHANGE IN BASIC MATERIAL USE

- SUBSTITUTION OF ONE MATERIAL FOR ANOTHER HAS SLOWED THE GROWTH OF DEMAND FOR PARTICULAR MATERIALS

- DESIGN CHANGES HAVE INCREASED THE EFFICIENCY OF MATERIALS USE

- SATURATION OF MARKETS WHICH WERE PREVIOUSLY EXPANDING HAS OCCURRED

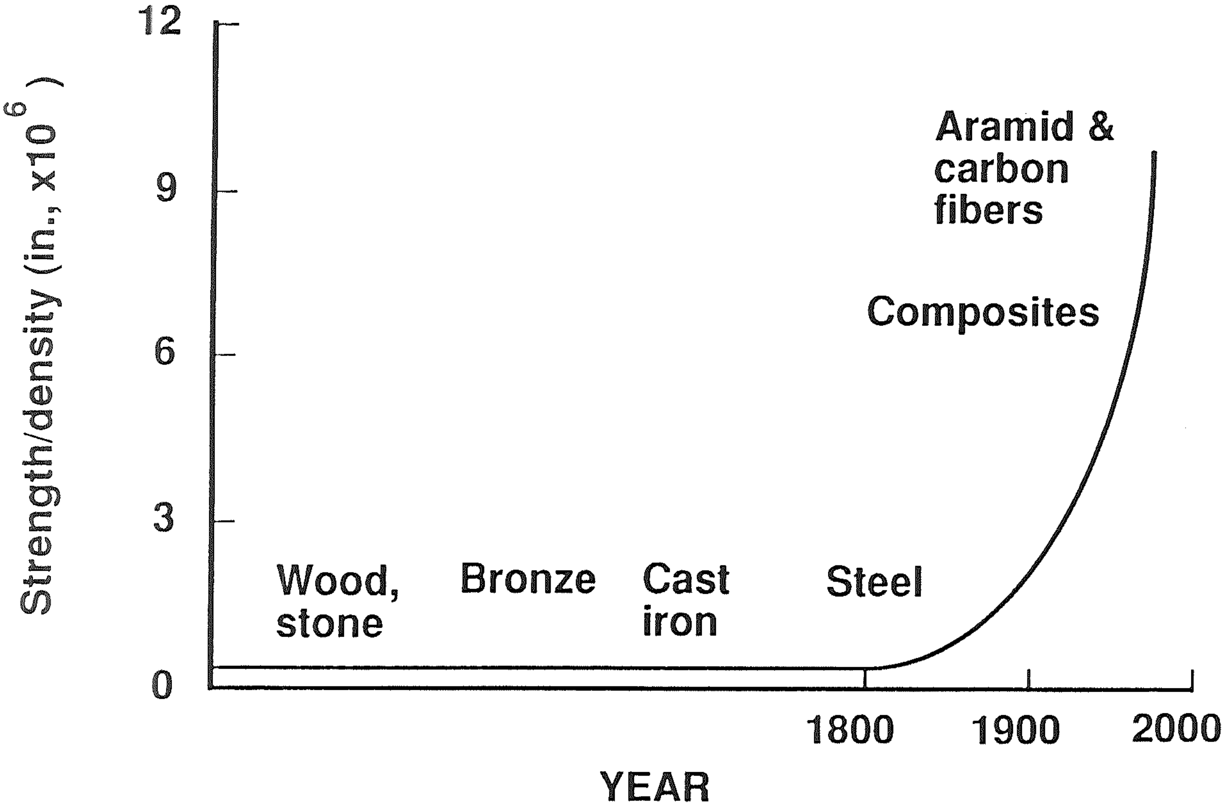
- LOW MATERIALS CONTENT IN PRODUCTS FOR NEW MARKETS, PARTLY BECAUSE OF THE COST OF HIGHER PERFORMANCE MATERIALS

MARKET DEMAND IS NOW LIGHTER, STRONGER, MORE DURABLE MATERIALS

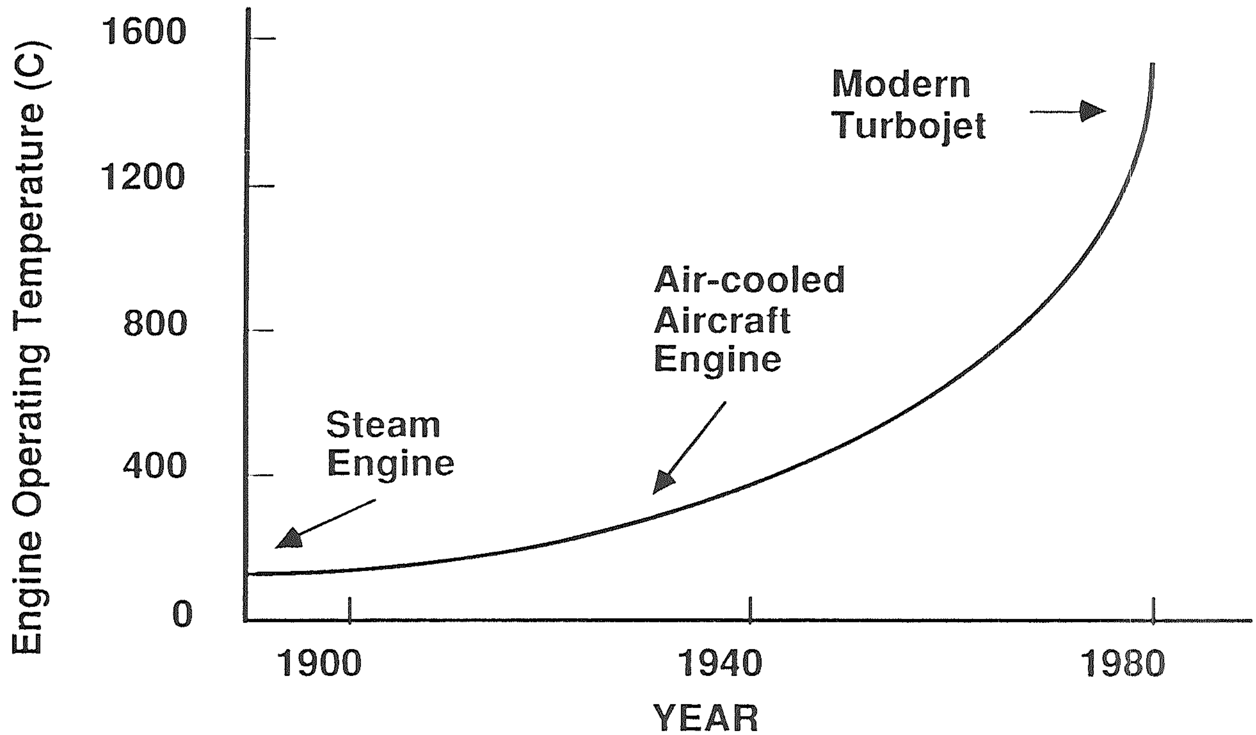
Desired Characteristic	Aero.	Auto	Bio	Chem.	Elec.	Energy	Metal	Tele.
Light / strong	✓	✓	✓					
High temp resist.	✓			✓	✓	✓	✓	
Corrosion resist.	✓	✓	✓	✓	✓	✓	✓	
Efficient processing	✓	✓	✓	✓	✓	✓	✓	✓
Near-net-shape	✓	✓	✓	✓	✓	✓	✓	✓
Prediction of life	✓	✓	✓	✓	✓	✓	✓	✓
Prediction of properties	✓	✓	✓	✓	✓	✓	✓	✓
Materials data bases	✓	✓	✓	✓	✓	✓	✓	✓

(Materials Science and Engineering for the 1990s)

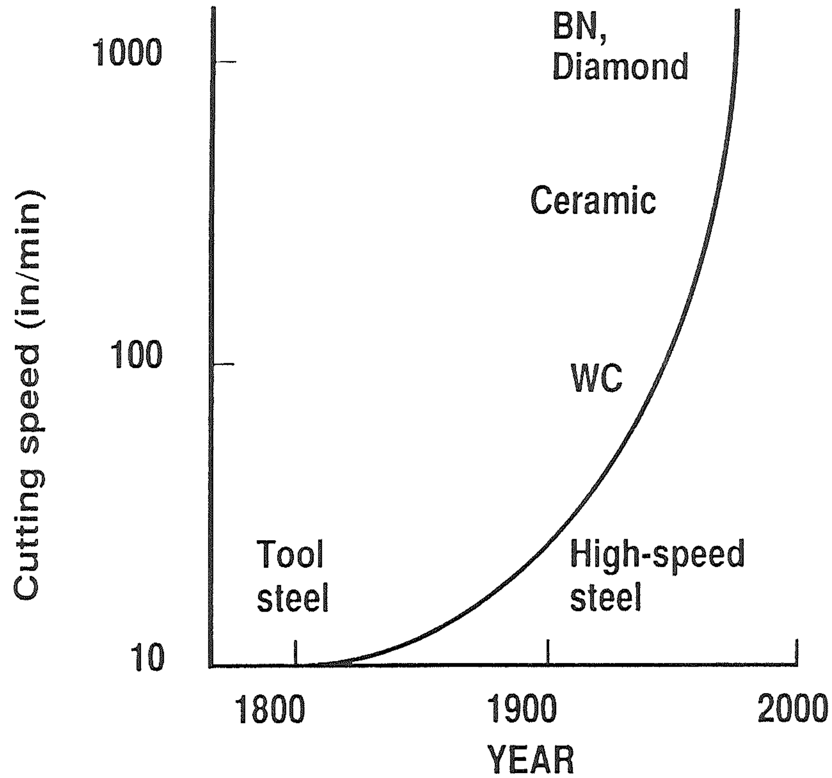
MODERN MATERIALS 50X HIGHER STRENGTH-TO-DENSITY RATIO THAN CAST IRON



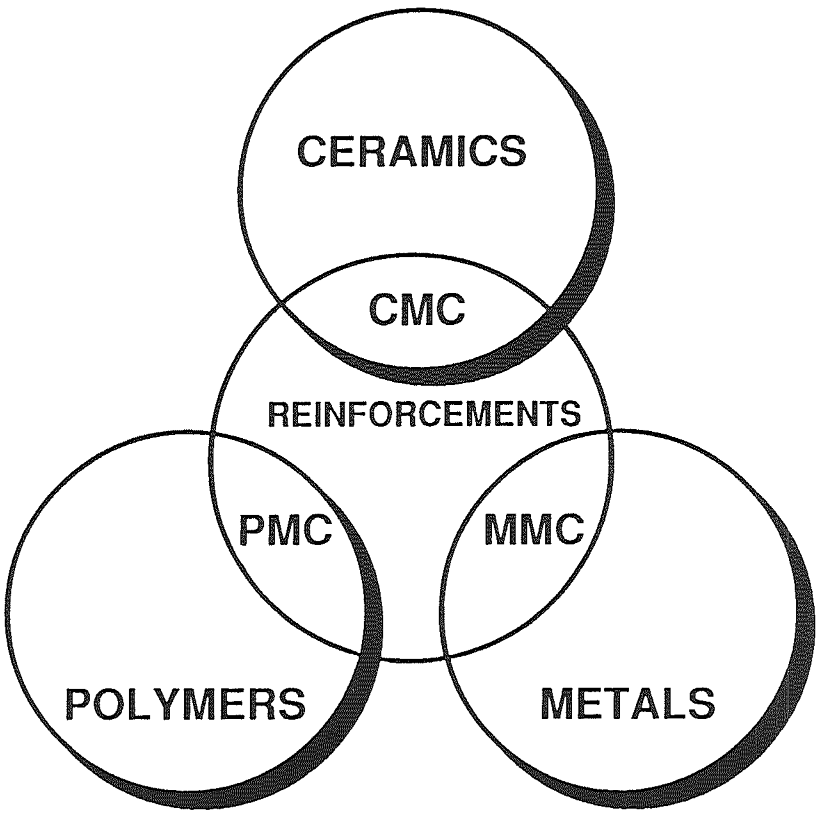
MODERN MATERIALS ENABLE HIGHER ENGINE OPERATING TEMPERATURES



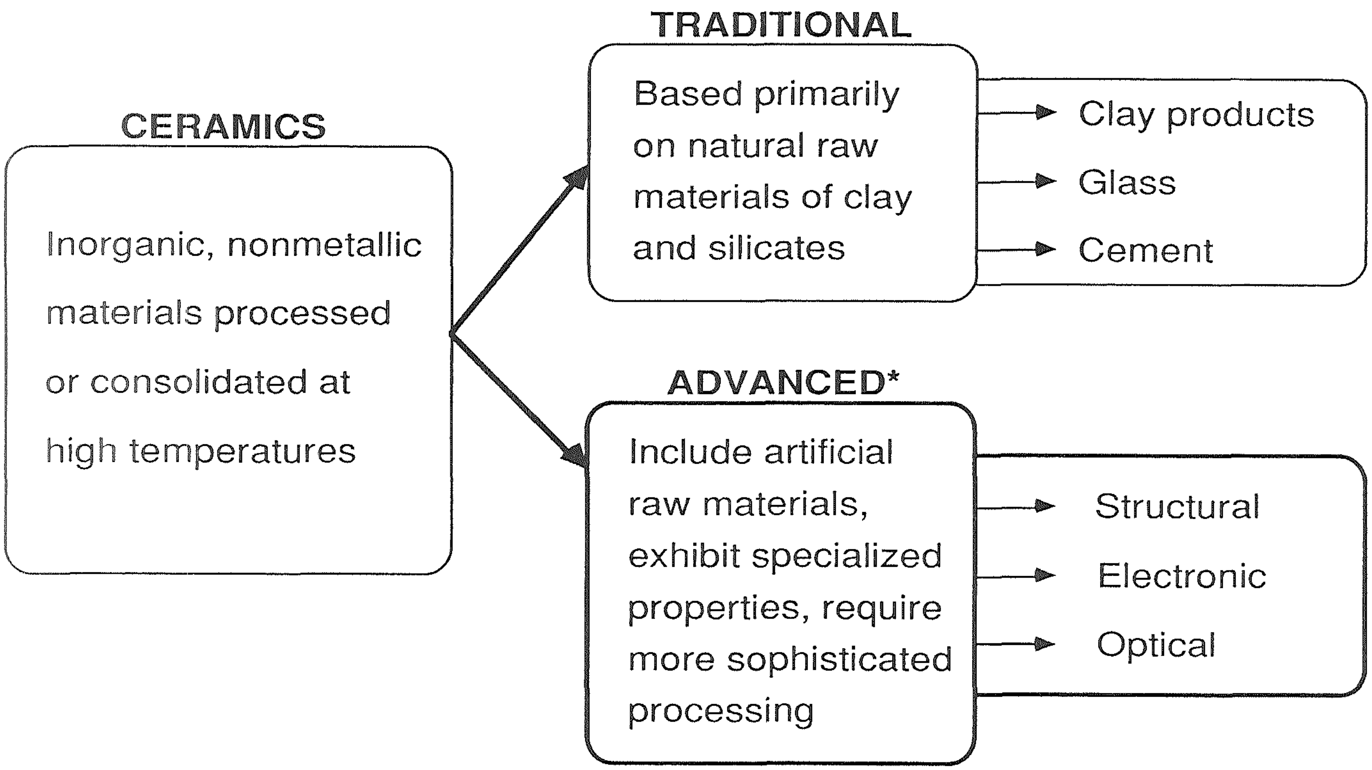
MATERIALS ENABLED EXPONENTIAL INCREASE IN CUTTING TOOL SPEED



THE PORTFOLIO OF ADVANCED MATERIALS



STRUCTURAL CERAMICS ARE LEADING CANDIDATES FOR MANY APPLICATIONS



* Fine ceramics, Engineered ceramics, New ceramics, Value-added ceramics

THE APPEAL OF STRUCTURAL CERAMICS IS EASY TO UNDERSTAND

Desired Characteristic	
Light / strong	Light with compressive strength > or = metals
High temp resist.	Withstand extreme temperatures
Corrosion resist.	Chemically inert, hard, abrasion resistant
Efficient processing	
Near-net-shape	
Prediction of life	
Prediction of properties	
Materials data bases	

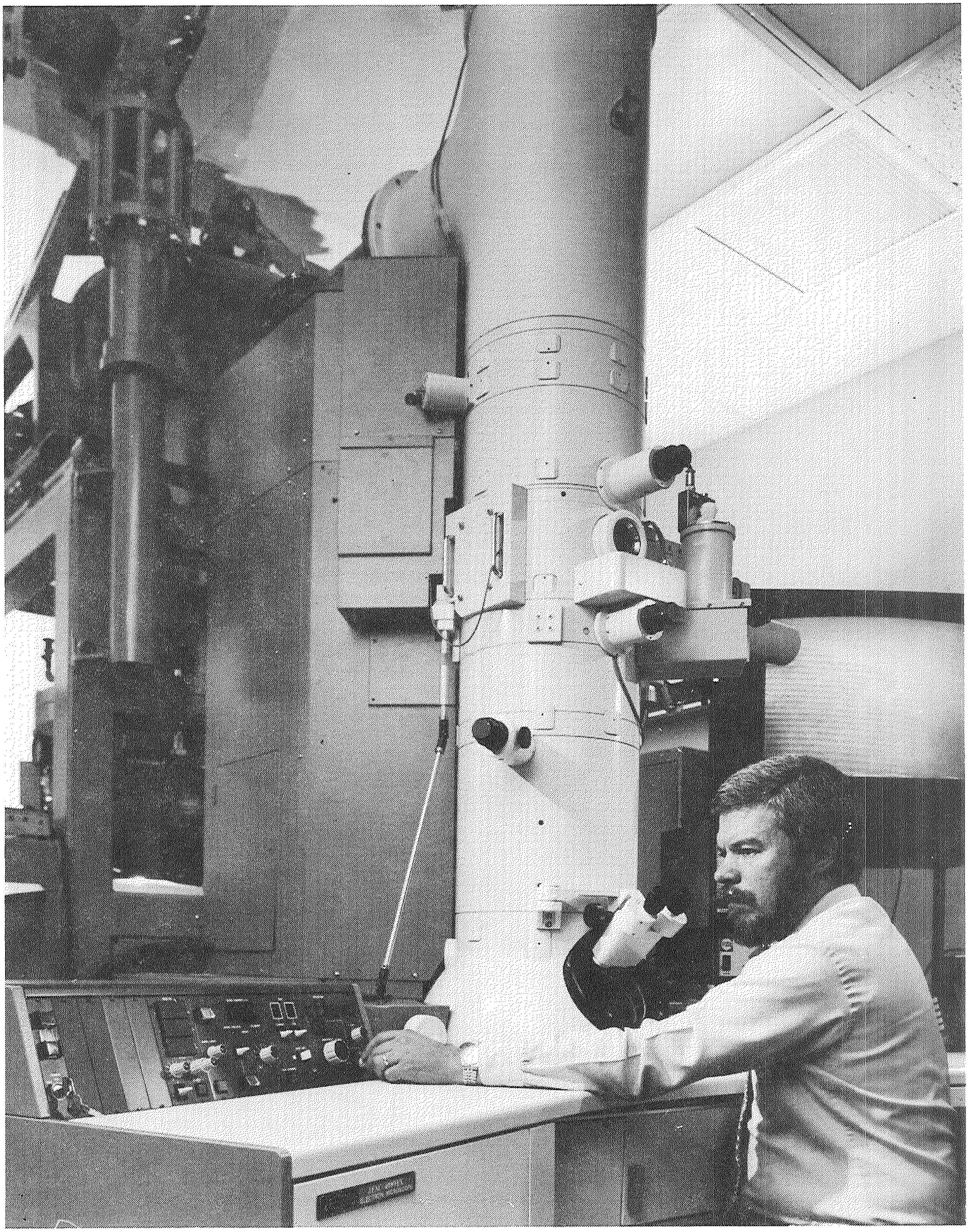
BUT REALIZING THESE PROPERTIES REQUIRES A LEVEL OF MICROSTRUCTURAL AND CHEMICAL PERFECTION FAR BEYOND THAT OF TRADITIONAL CERAMICS

STRUCTURAL CERAMICS ARE A RESULT OF A FEW KEY DEVELOPMENTS

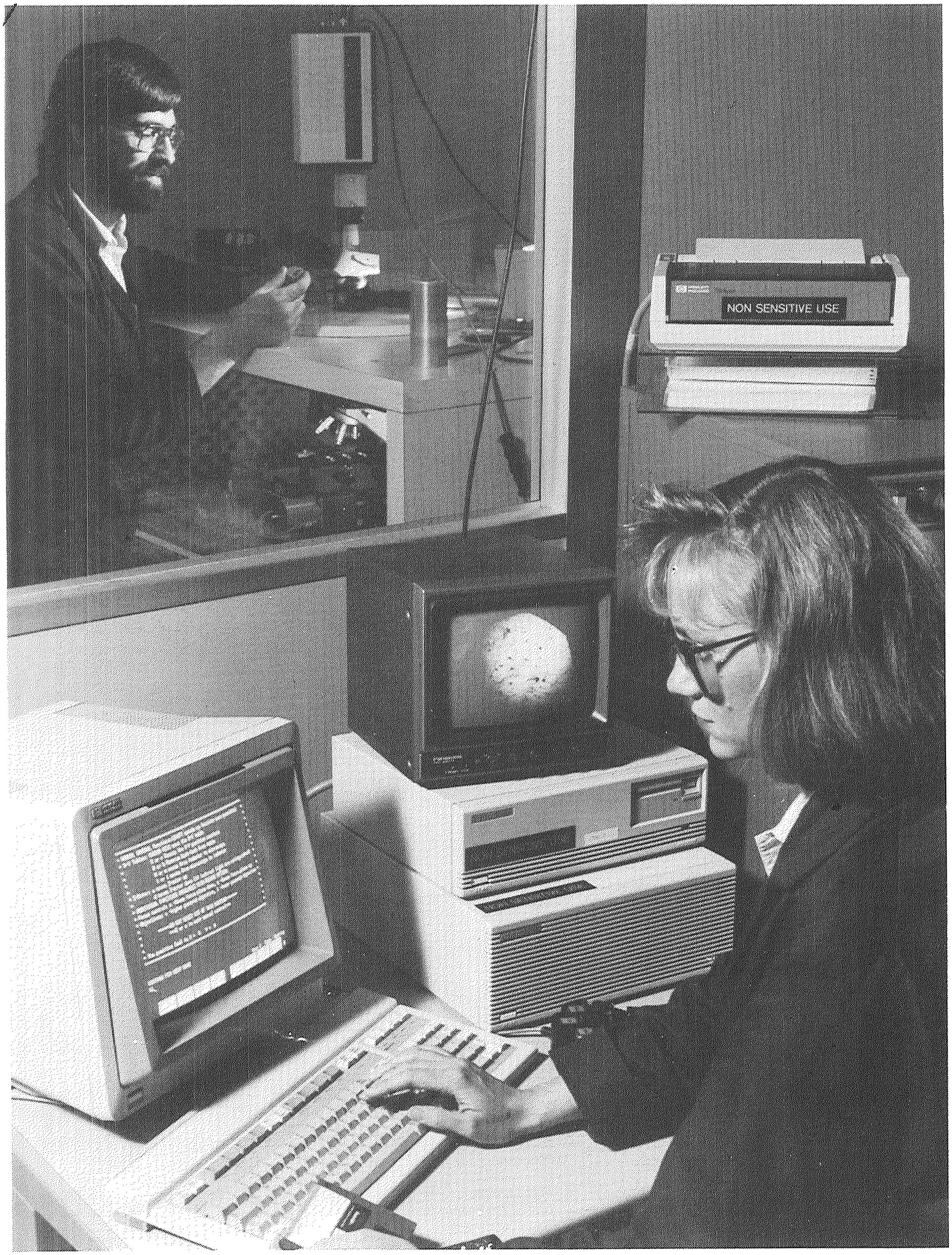
	TRADITIONAL +	DEVELOPMENT =	ADVANCED
MATERIALS	NATURAL	SYNTHETIC MATERIALS PREPARATION	SYNTHETIC (CONTRIVED)
ANALYSIS	OPTICAL, MACRO	XRD, ELECTRON MICROSCOPY	MICRO-ANALYSIS
PROCESSING	HISTORIC, TOLERANT	RELATIONS OF PROCESSING & PROPERTIES	UNIFORM CHEMISTRY & STRUCTURE

1800 — 1930 — 1950 — 1990

SOPHISTICATED MICROSCOPY ALLOWS DETERMINATION OF MICROSTRUCTURE



MECHANICAL PROPERTIES CAN BE DETERMINED AT THE MICROSTRUCTURAL LEVEL



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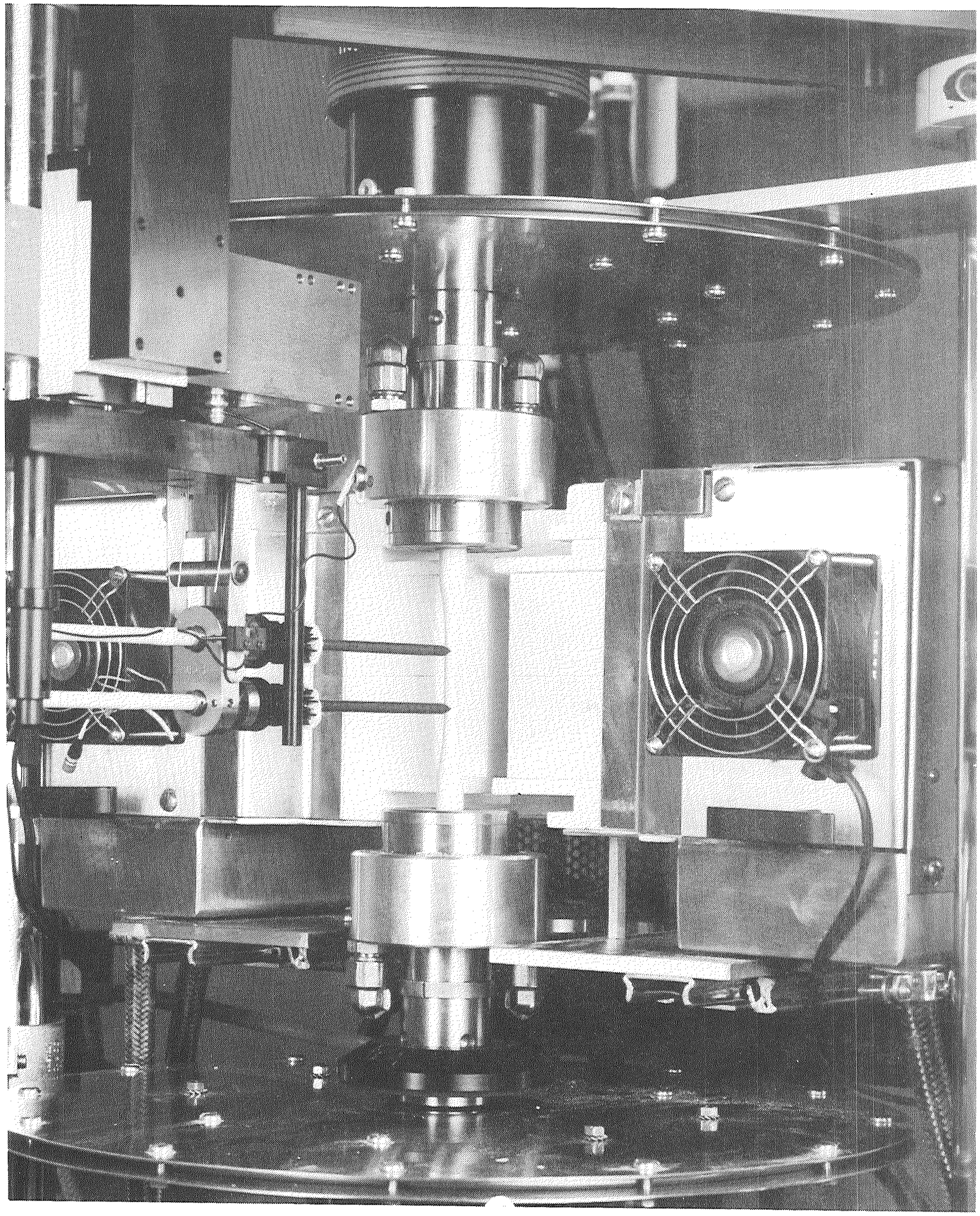
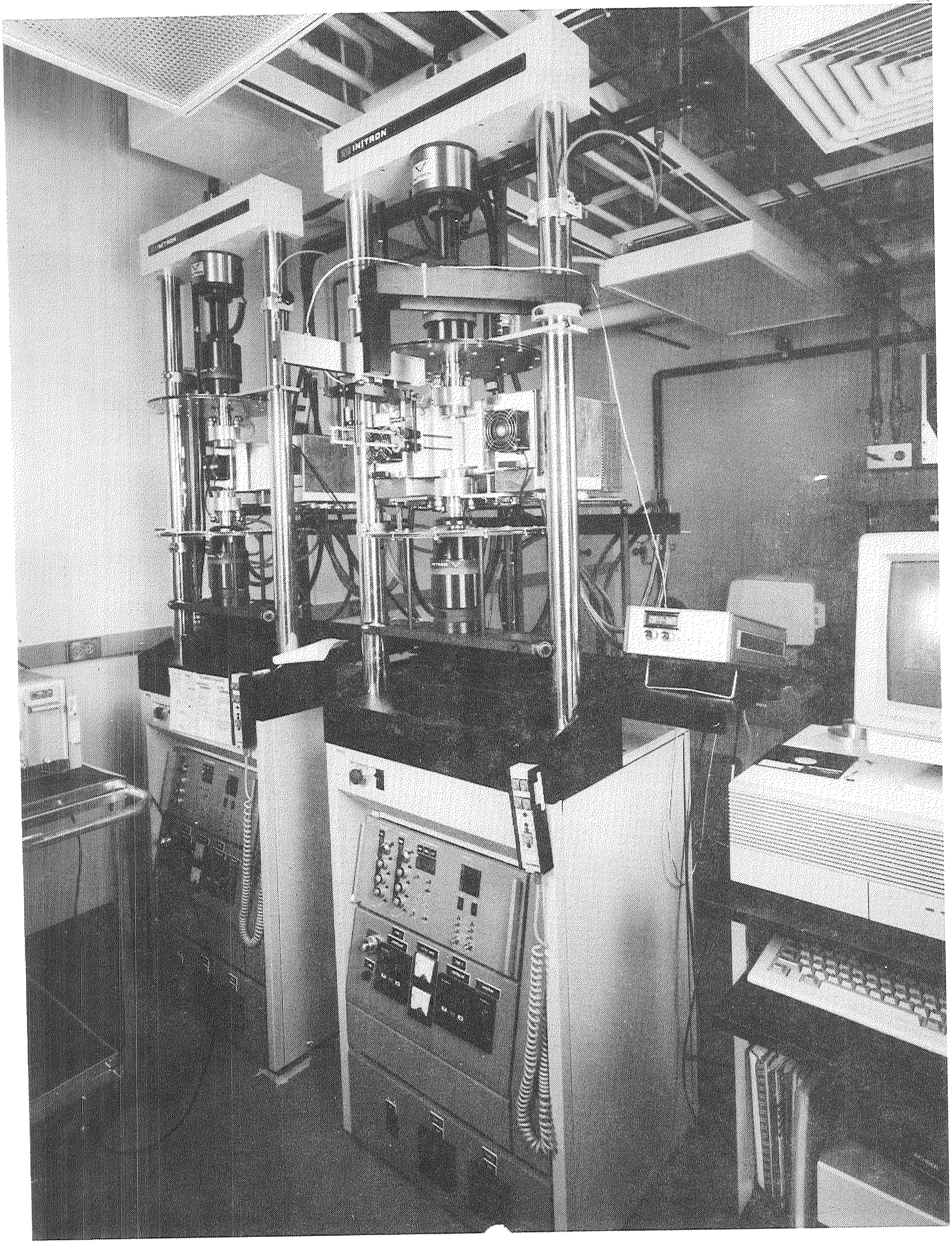
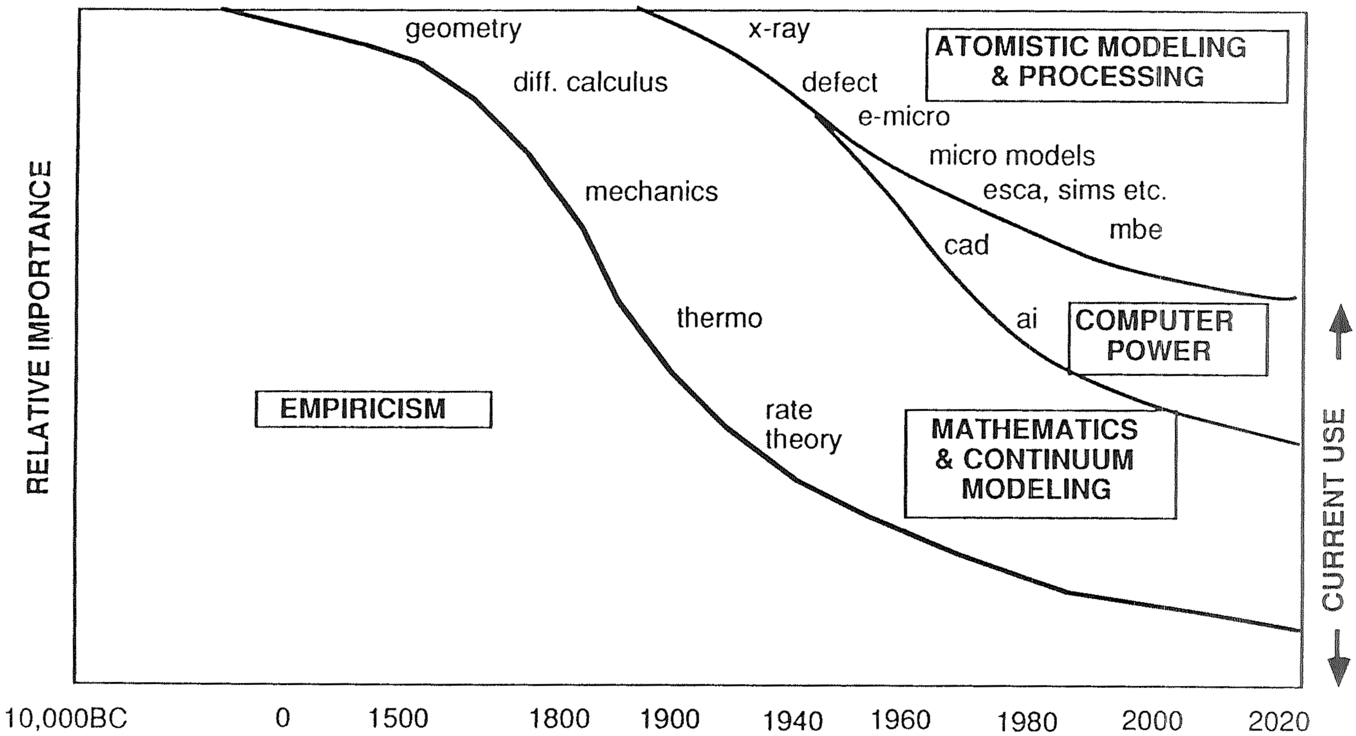
TENSILE TESTER—SPECIALIZED EQUIPMENT FOR DETERMINING CERAMIC MECHANICAL PROPERTIES



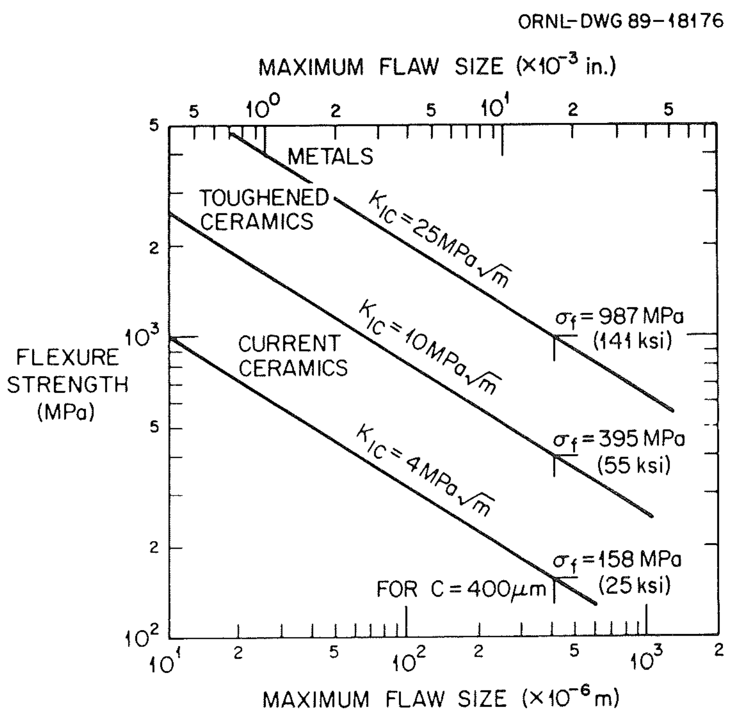
TENSILE TESTER—FULL VIEW

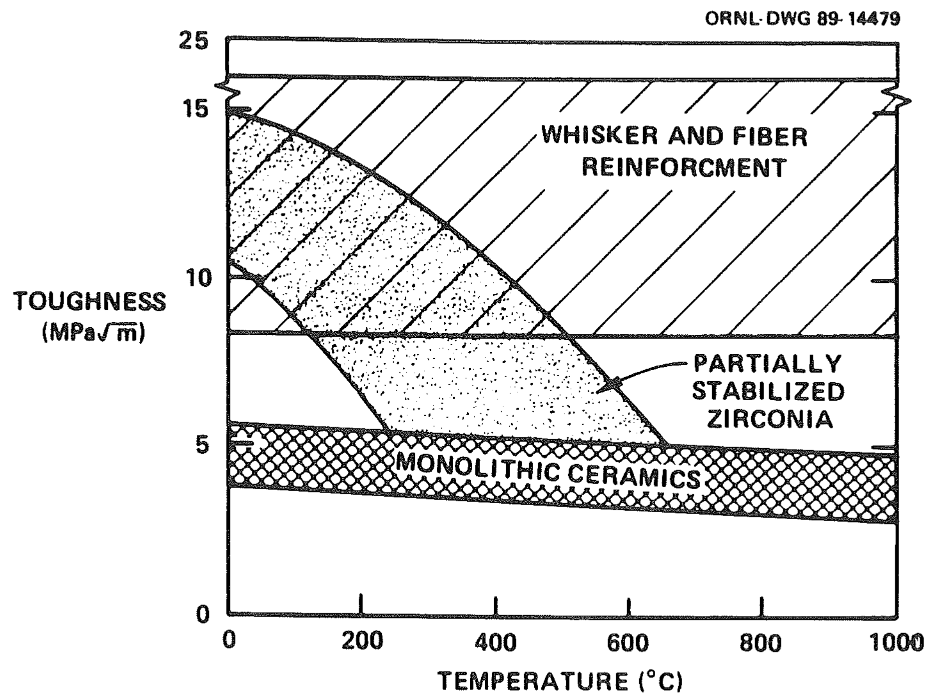


ADVANCES IN CERAMICS WILL BE BASED ON ATOMISTIC MODELING, TAILORED MICROSTRUCTURE AND SOPHISTICATED PROCESSING

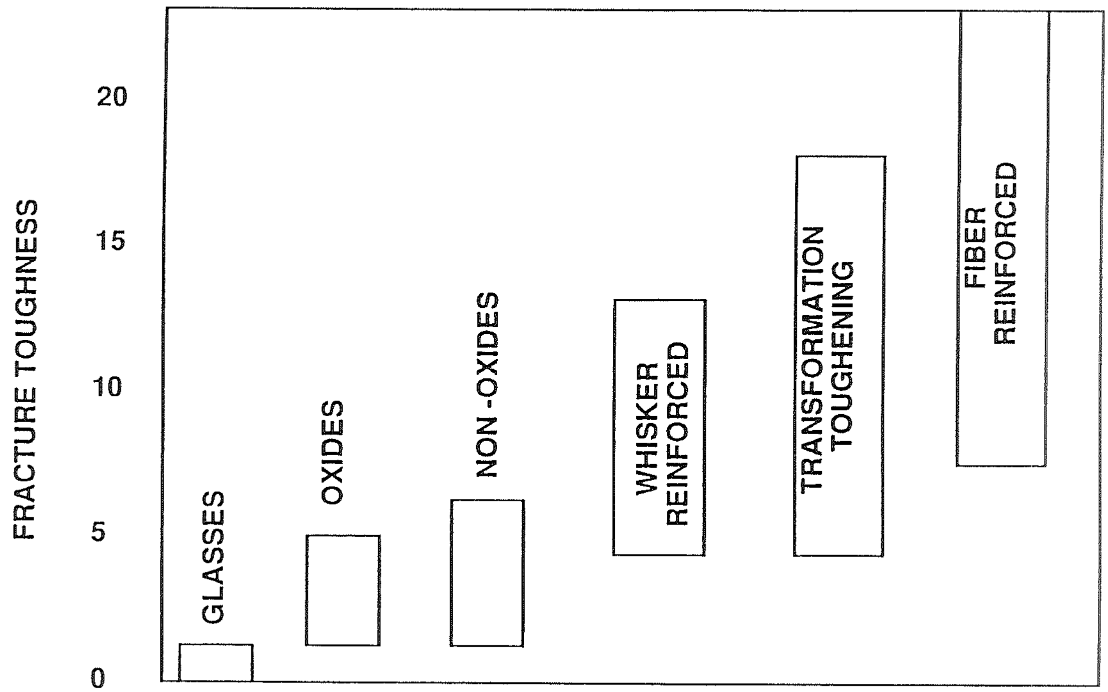


TOUGHENING IS REQUIRED TO MAKE CERAMICS VIABLE FOR STRUCTURAL APPLICATIONS





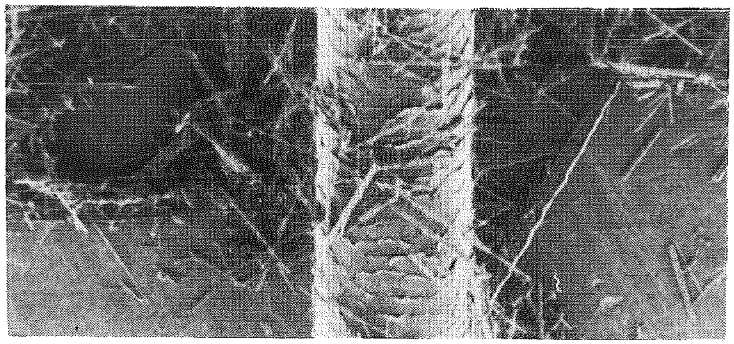
MICROSTRUCTURE TAILORING & NOVEL COMPOSITE DESIGN ADDRESS INHERENT BRITTLENESS OF CERAMICS



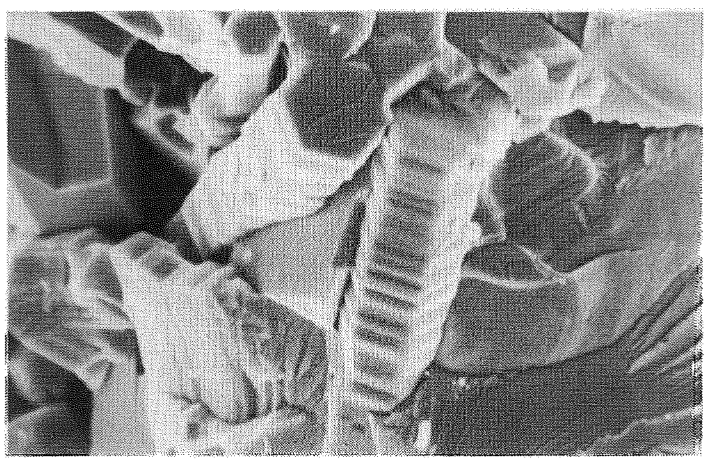
COMPARED TO METALS WITH TYPICAL FRACTURE TOUGHNESS OF 15-200

FRACTURE RESISTANCE IS INCREASED BY REINFORCING CERAMICS WITH STRONG MICROSCOPIC WHISKERS

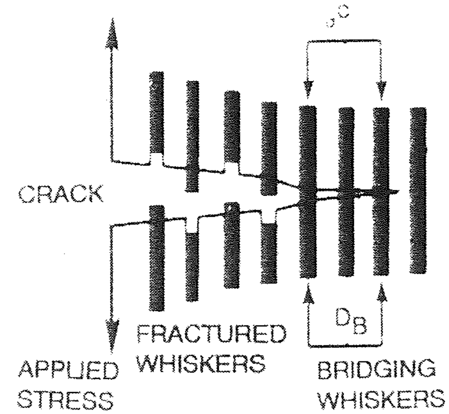
Ceramic Whiskers and Human Hair



Ceramic Composite Fracture Surface



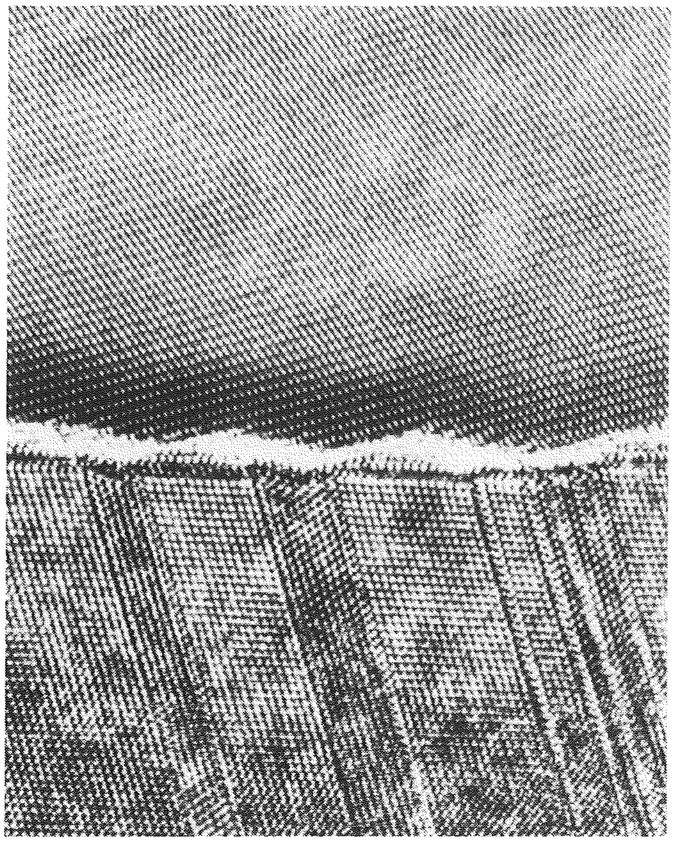
Toughness Model



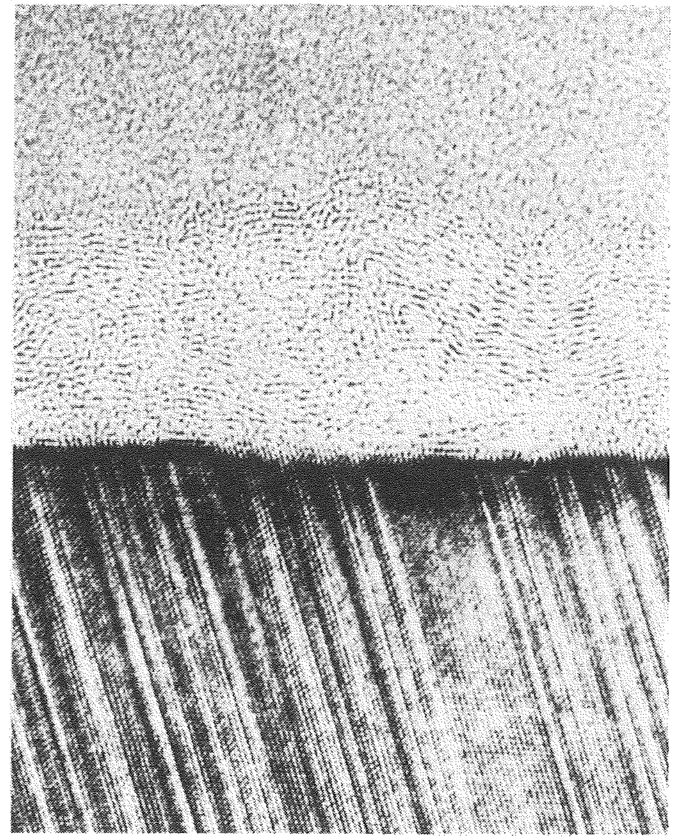
$$dK^{wr} = \sigma^{W}\left[\frac{V\,r}{6(1-\nu^{2})}\,\frac{E^{C}}{E^{W}}\,\frac{G^{M}}{G^{I}}\right]^{1/2}$$

σ^W = Fracture strength whisker
V = Vol. fracture whiskers
r = Whisker radius
E = Young's modulus
G = Fracture Energy

R&D ADDRESSING EFFECTS OF WHISKER COATINGS ON COMPOSITE PROPERTIES



Alumina-SiC whisker interface



Carbon coated whisker-alumina interface

SILICON CARBIDE WHISKER-TOUGHENED ALUMINA CERAMICS

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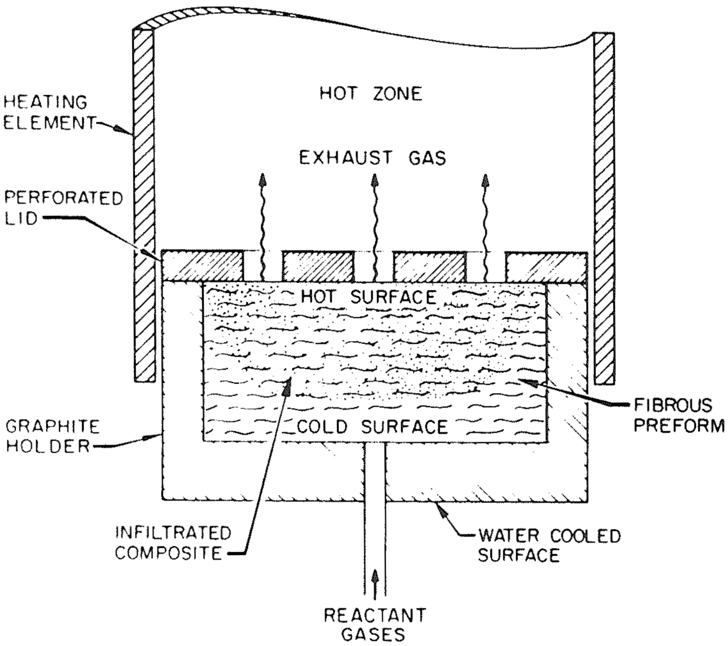
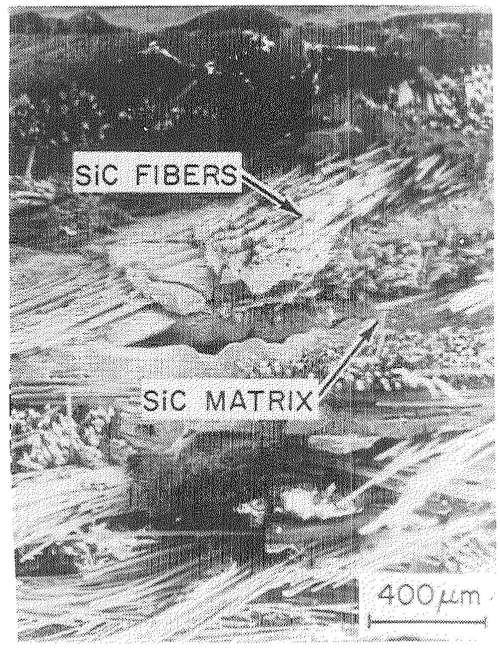
ORNL-PHOTO 7104-88R

FIBER-REINFORCED CERAMIC COMPOSITES HAVE BEEN FABRICATED USING A FORCED CHEMICAL VAPOR INFILTRATION PROCESS





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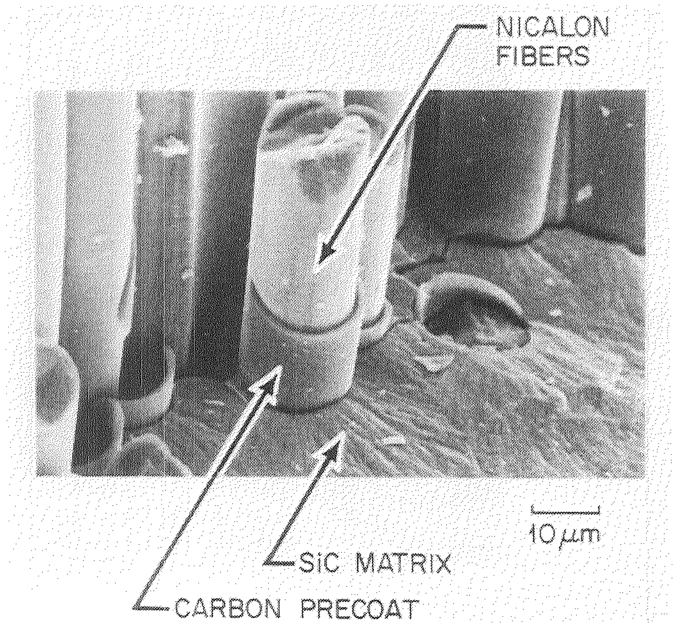
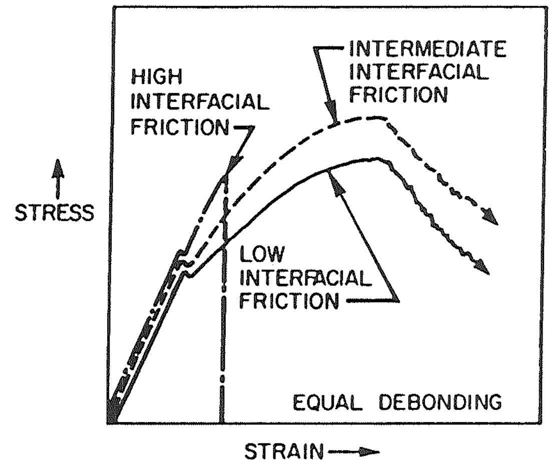
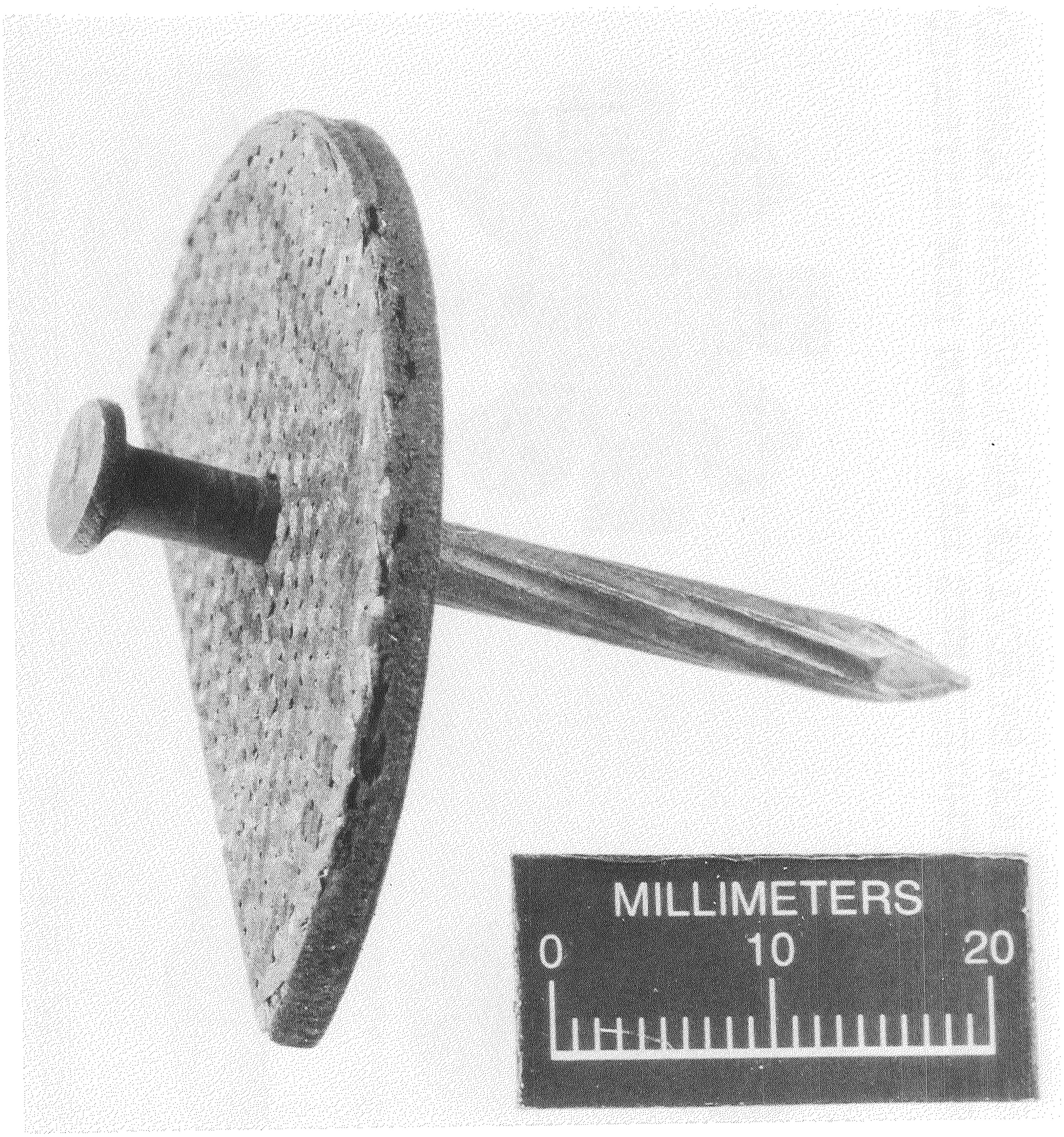
EXPERIMENTAL RESULTS SHOW MODIFICATION OF MATRIX/ WHISKER INTERFACE IMPROVES COMPOSITE TOUGHNESS

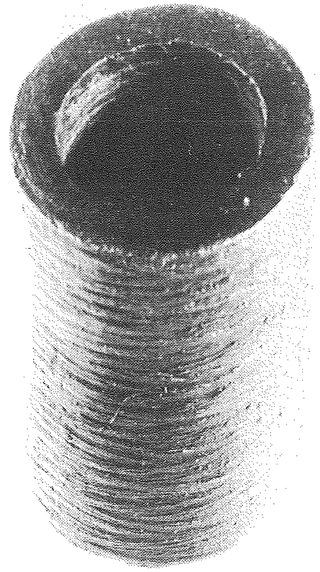




TOUGH, CONTINUOUS-FIBER CERAMIC COMPOSITE

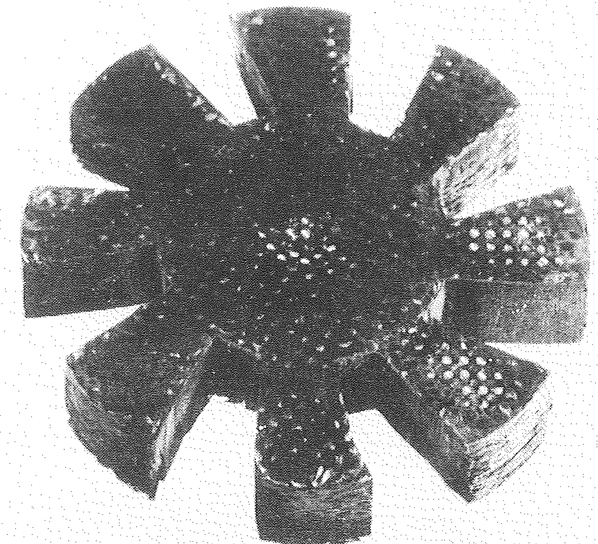


SUCCESSFUL FABRICATION BY FCVI OF ARTICLES WITH COMPLEX SHAPES AND FIBER ARCHITECTURES HAS BEEN DEMONSTRATED

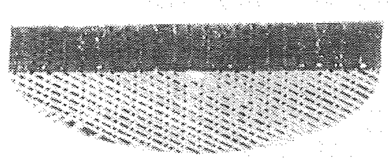


ANGLE-WOUND TUBE

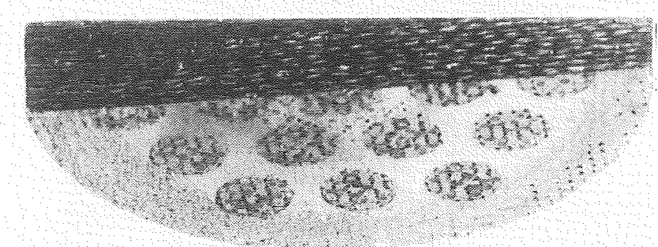
0 10 20
MILLIMETERS



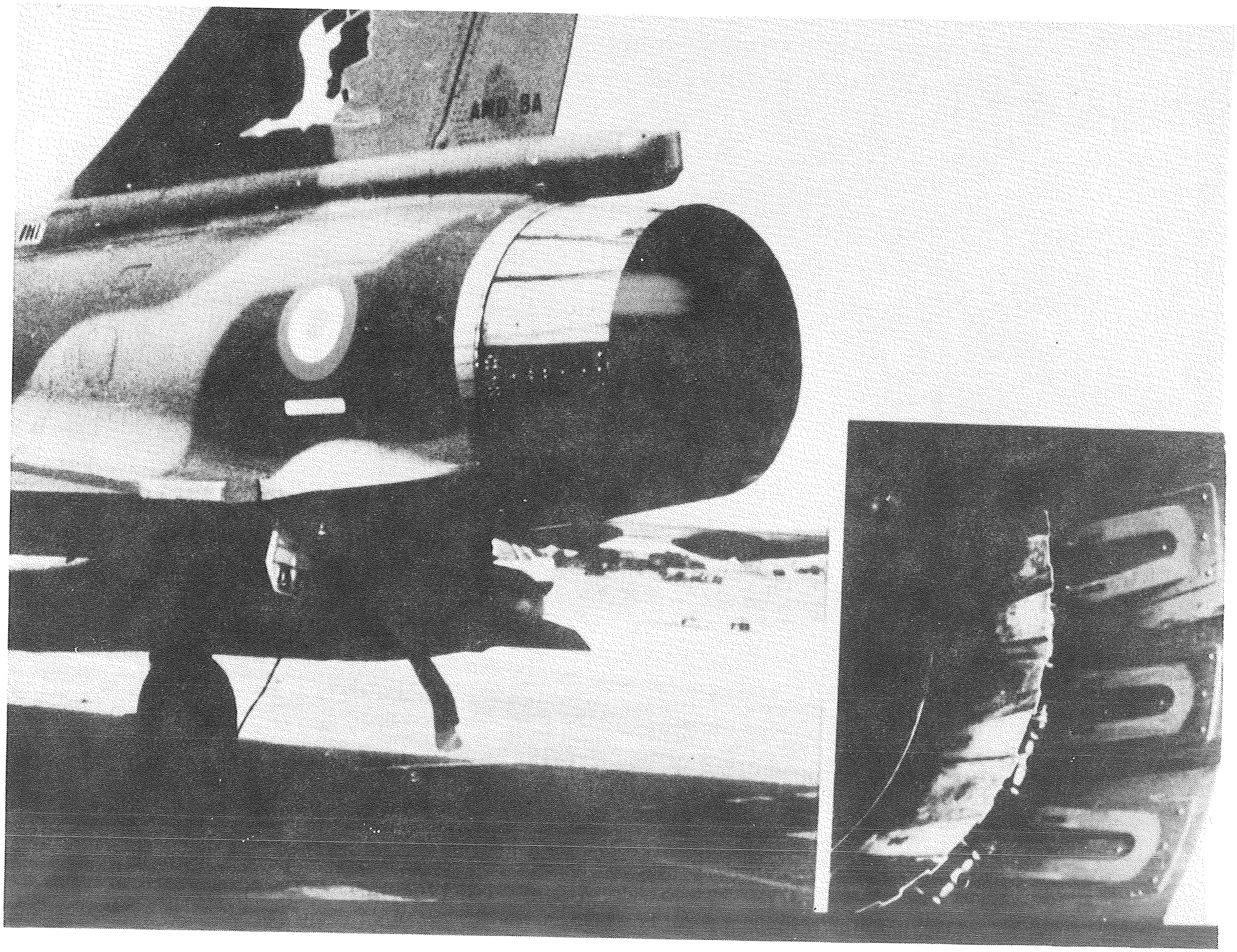
REPRESENTATIVE ROTOR
(cloth layup)

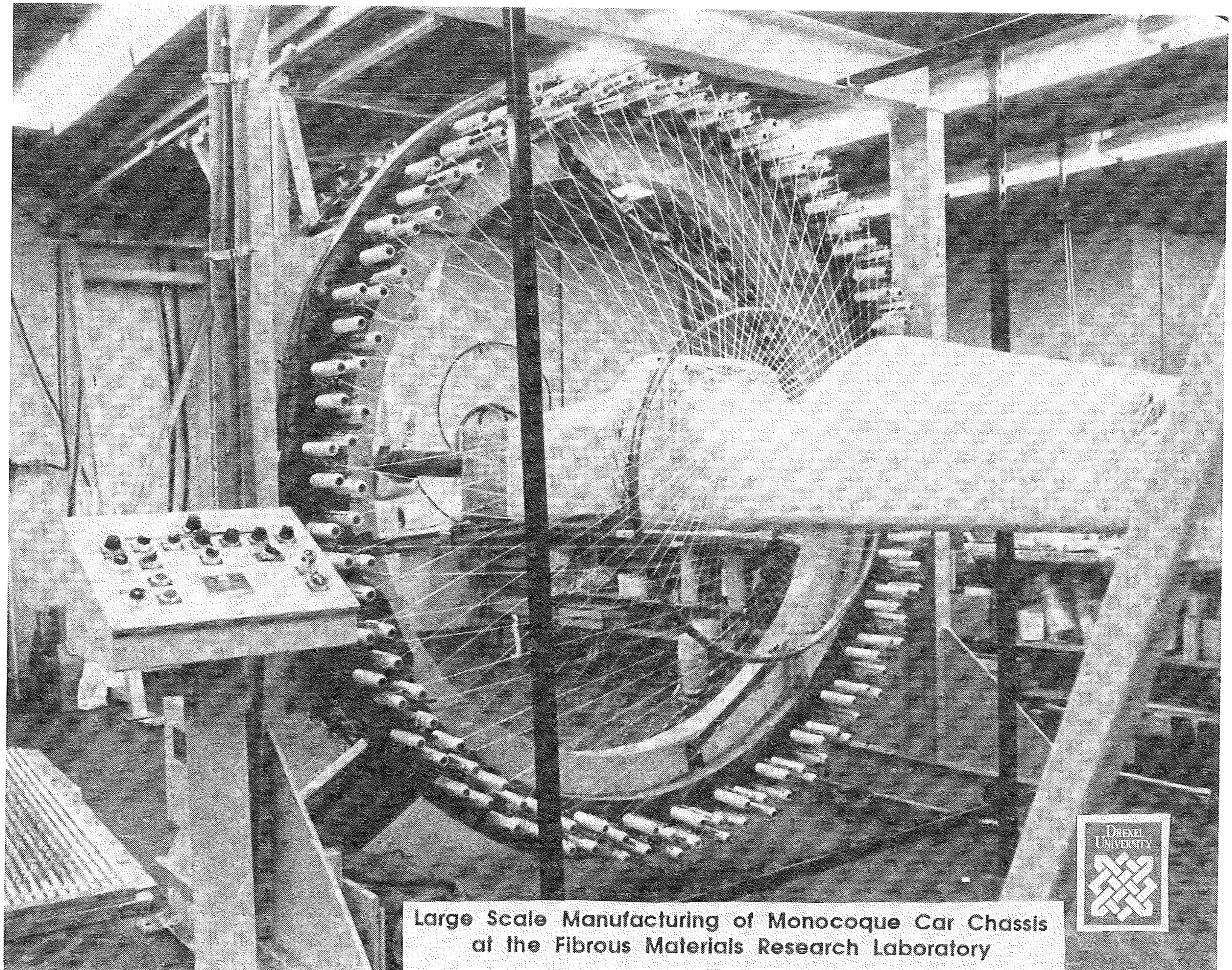


3-D ORTHOGONAL WOVEN DISK



THICK-TO-THIN DISK
(cloth layup)

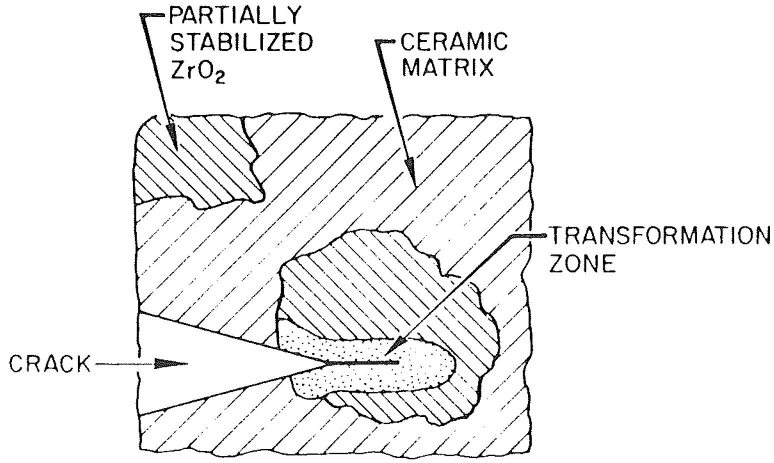


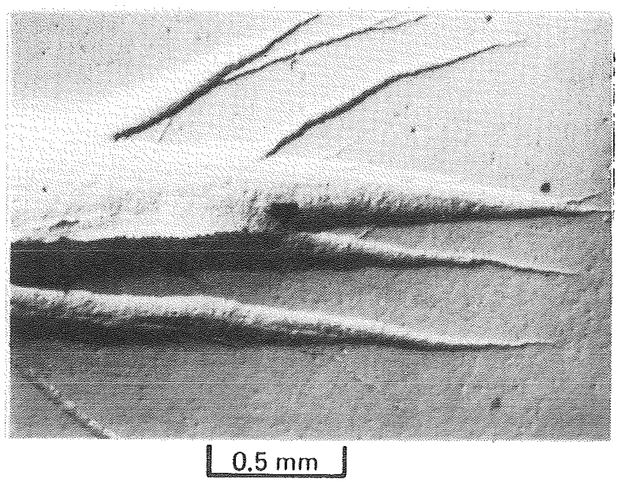


Large Scale Manufacturing of Monocoque Car Chassis
at the Fibrous Materials Research Laboratory

ADDITION OF ZrO_2 TO BRITTLE CERAMICS INCREASES RESISTANCE TO CRACK PROPAGATION

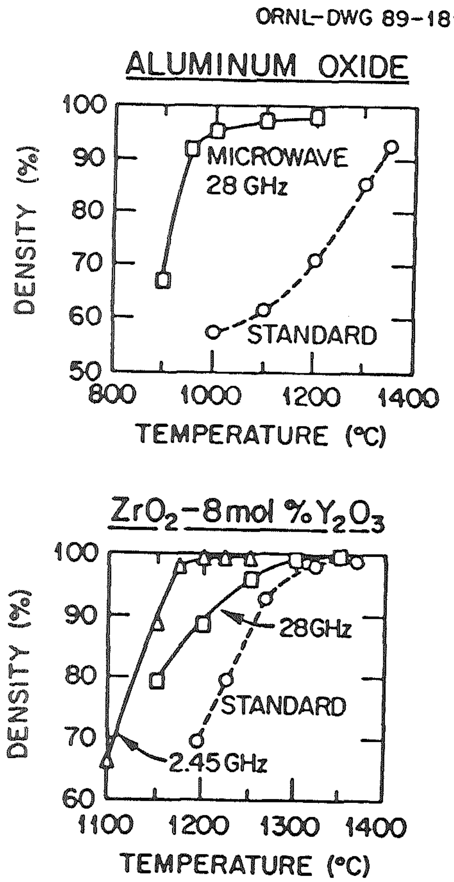
ORNL-DWG 89-18172





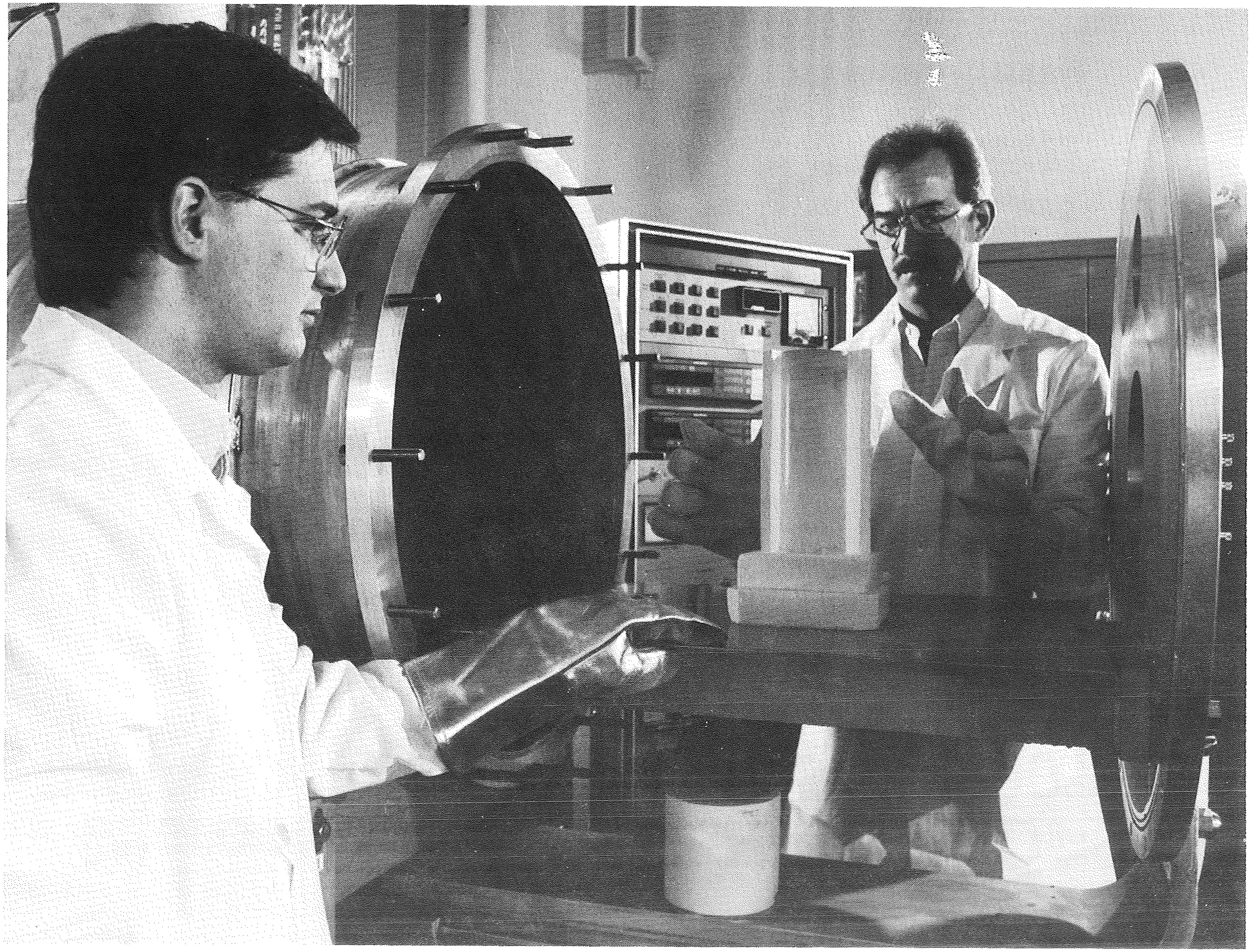
- Toughening is derived from stress-induced martensitic transformation in ZrO_2 particles
  - Transformation consumes energy needed for further propagation
  - Increased volume of new phase contributes compressive forces resisting further propagation

MICROWAVE SINTERING HAS SIGNIFICANT IMPLICATIONS FOR NEW MATERIALS APPLICATIONS

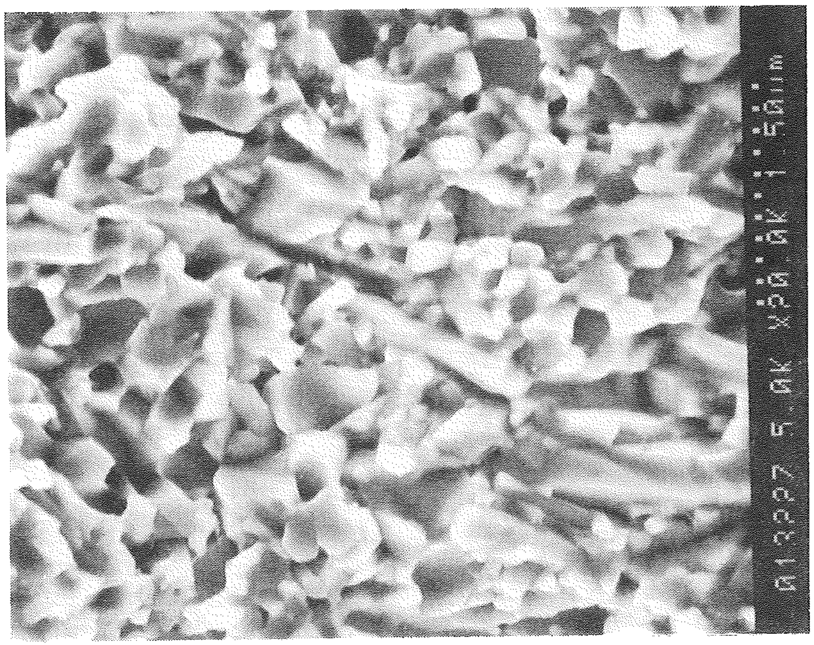


- Accelerated Kinetics:
  - Sintering occurs at lower temperatures
- Significant Potential Benefits
  - Lower temperature processing
  - Finer microstructures
  - Better mechanical properties
- Advanced Materials Applications:
  - Composites from incompatible materials
  - Self-lubricating high-temperature bearings
  - Electrical materials
  - Engine components

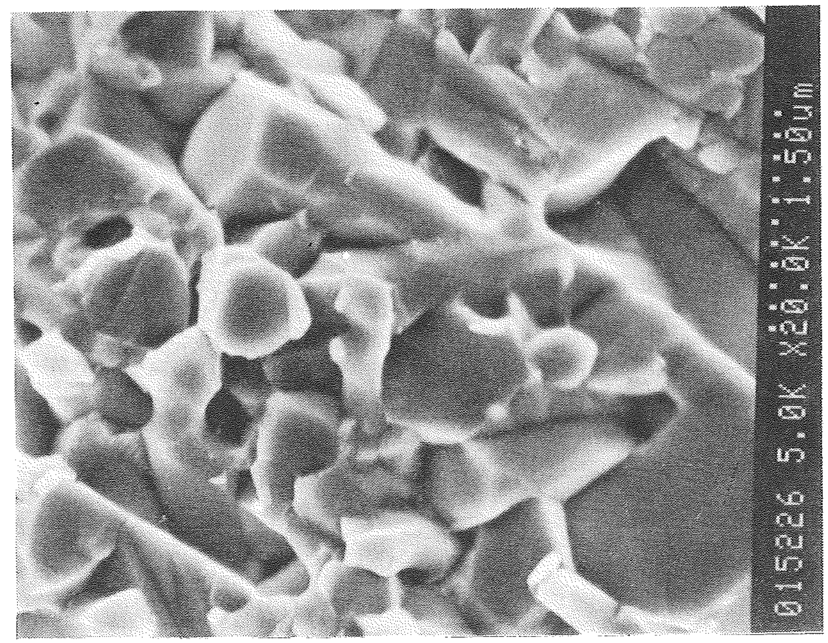
MICROWAVE FACILITY FOR DENSIFYING CERAMICS



Microstructure of Si_3N_4-6% Y_2O_3-2% Al_2O_3 After Annealing at 1200°C for 20 hours

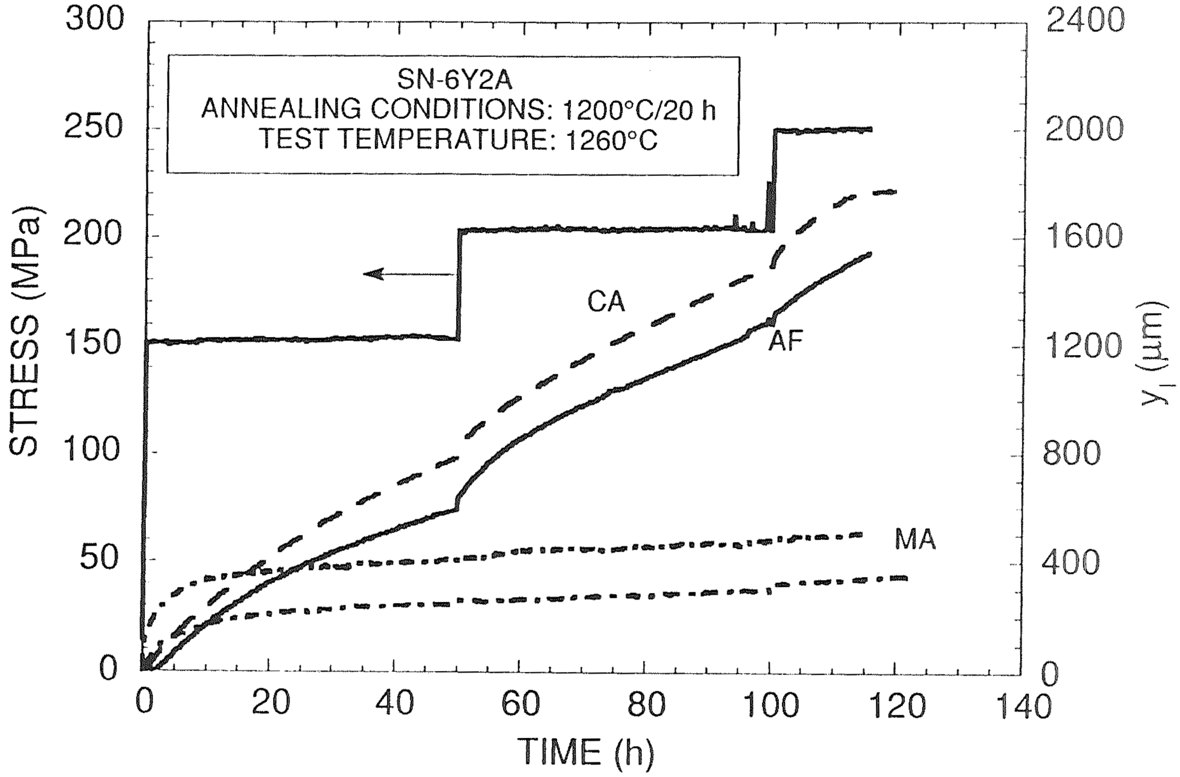


Conventional Heating

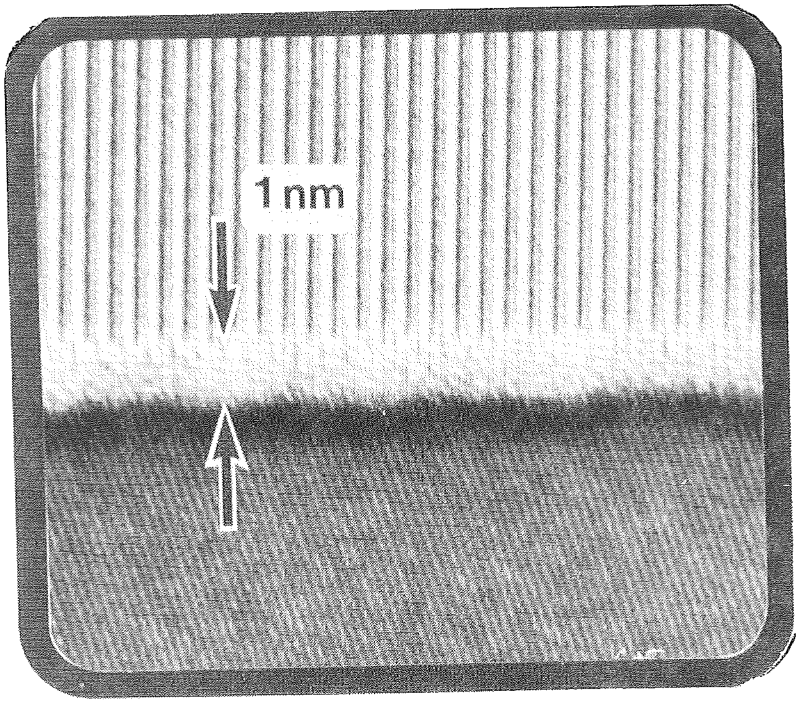


Microwave Heating

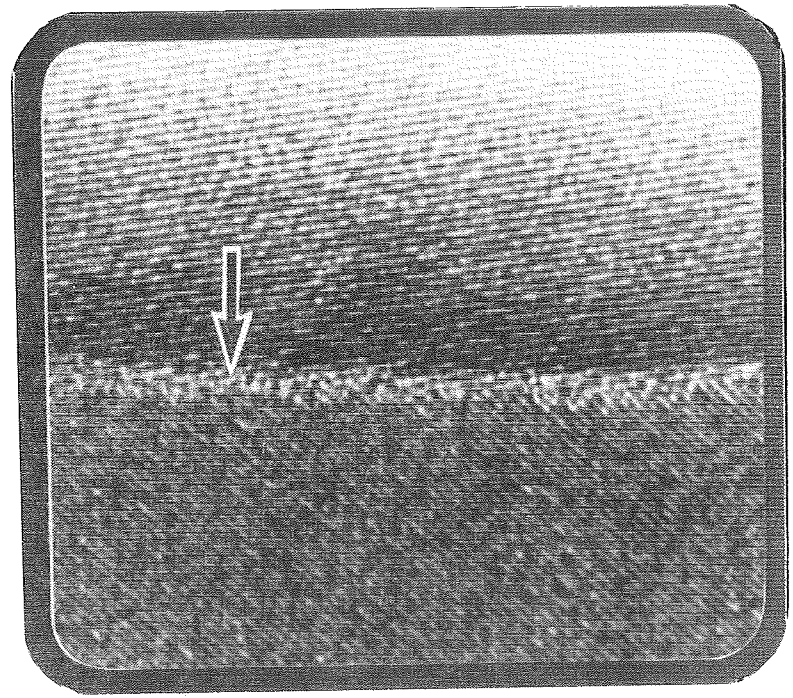
MICROSTRUCTURE MODIFICATION SIGNIFICANTLY IMPROVES CREEP RESISTANCE



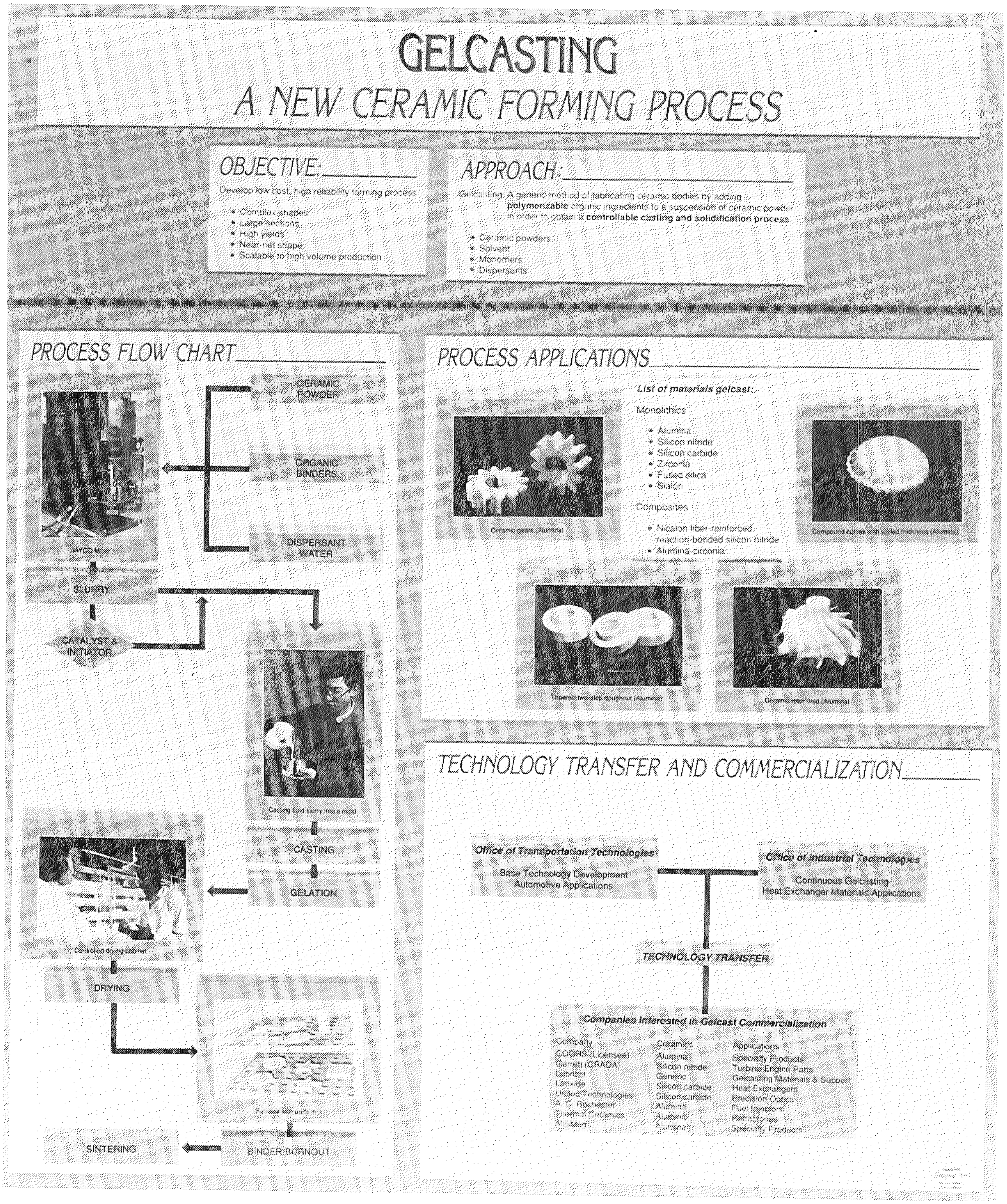
Tensile creep of NTX-154 and NT-164 at 1370°C

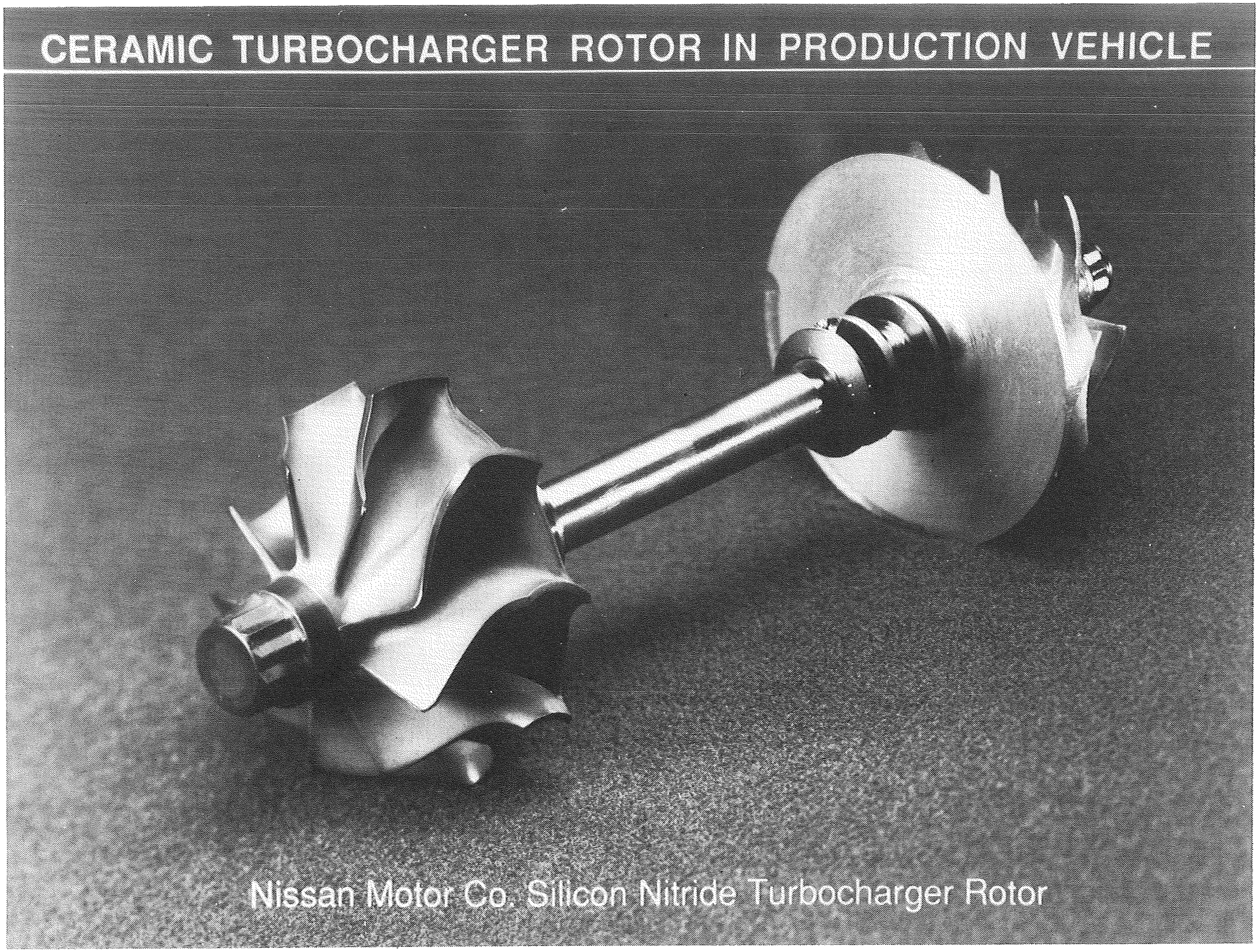


NTX-154 had a glass layer at most Si_3N_4/Si_3N_4 grain boundaries after creep (100 MPa, 1200 h).

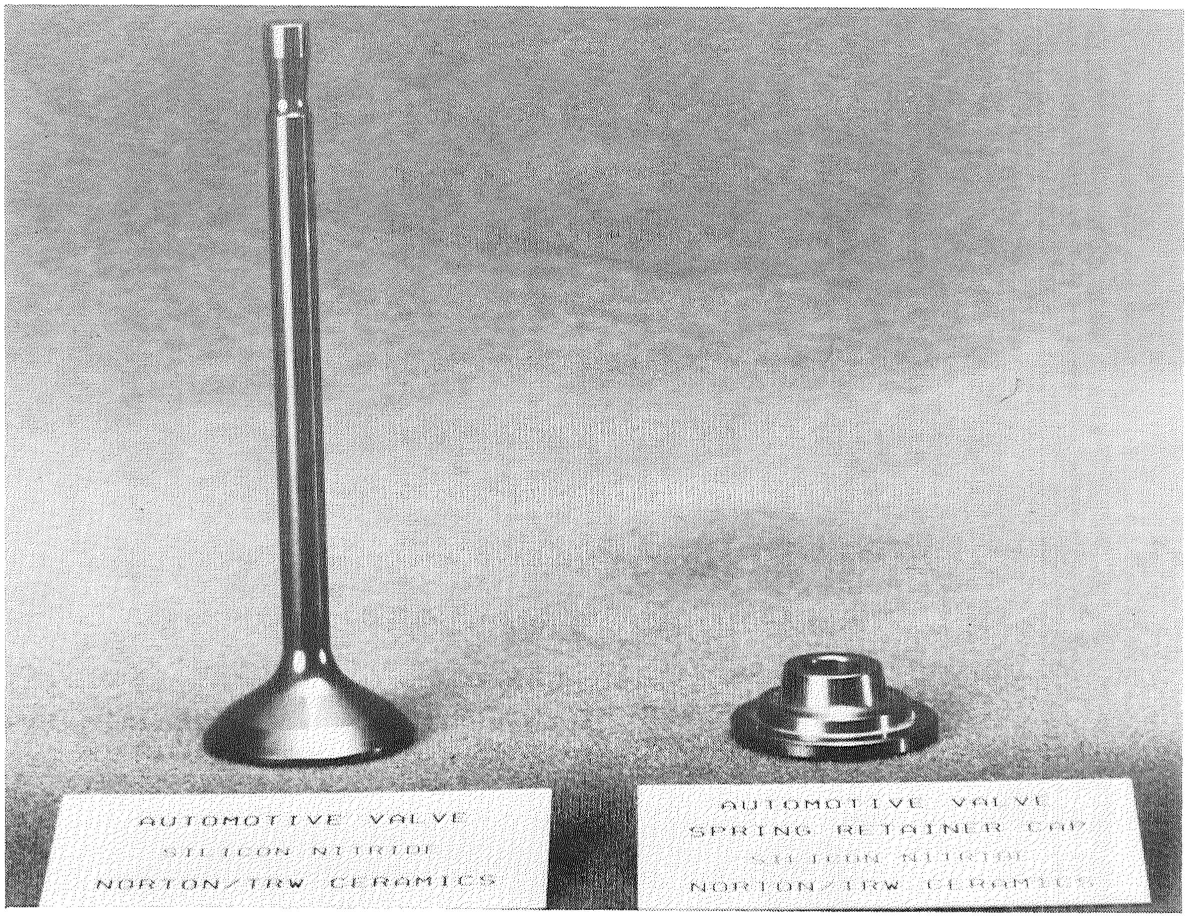


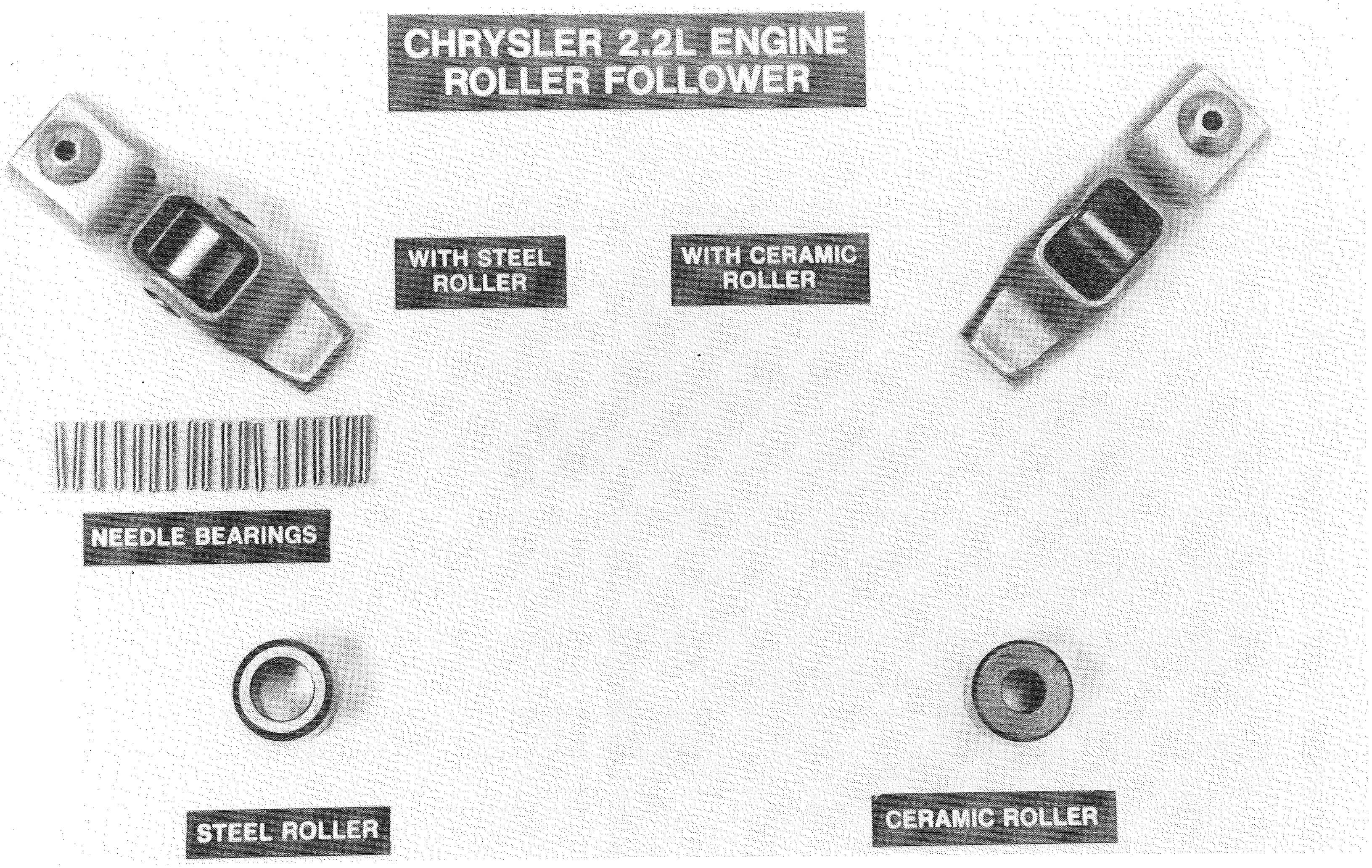
No glass layer was found at NT-164 Si_3N_4/Si_3N_4 grain boundaries after creep (150 MPa, 959 h).


GELCASTING
A NEW CERAMIC FORMING PROCESS
OBJECTIVE:
Develop low cost, high reliability forming process
• Complex shapes
• Large sections
• High yields
• Near-net shape
• Scalable to high volume production
APPROACH:
Gelcasting: A generic method of fabricating ceramic bodies by adding polymerizable organic ingredients to a suspension of ceramic powder in order to obtain a controllable casting and solidification process
• Ceramic powders
• Solvent
• Monomers
• Dispersants
PROCESS FLOW CHART
CERAMIC POWDER
ORGANIC BINDERS
DISPERSANT WATER
JAYCO Mixer
SLURRY
CATALYST & INITIATOR
Casting fluid slurry into a mold
CASTING
GELATION
Controlled drying cabinet
DRYING
BINDER BURNOUT
SINTERING
PROCESS APPLICATIONS
List of materials gelcast:
Monolithics
• Alumina
• Silicon nitride
• Silicon carbide
• Zirconia
• Fused silica
• Sialon
Composites
• Nicalon fiber-reinforced reaction-bonded silicon nitride
• Alumina-zirconia
Ceramic gears (Alumina)
Compound curves with varied thickness (Alumina)
Tapered two-step doughnut (Alumina)
Ceramic rotor fired (Alumina)
TECHNOLOGY TRANSFER AND COMMERCIALIZATION
Office of Transportation Technologies
Base Technology Development
Automotive Applications
Office of Industrial Technologies
Continuous Gelcasting
Heat Exchanger Materials/Applications
TECHNOLOGY TRANSFER
Companies Interested in Gelcast Commercialization
Company | Ceramics | Applications
COORS (Licensee) | Alumina | Specialty Products
Garrett (CRADA) | Silicon nitride | Turbine Engine Parts
Lubrizol | Generic | Gelcasting Materials & Support
Lanxide | Silicon carbide | Heat Exchangers
United Technologies | Silicon carbide | Precision Optics
A. C. Rochester | Alumina | Fuel Injectors
Thermal Ceramics | Alumina | Refractories
AlSiMag | Alumina | Specialty Products


CERAMIC TURBOCHARGER ROTOR IN PRODUCTION VEHICLE
Nissan Motor Co. Silicon Nitride Turbocharger Rotor

EXTENDED VEHICLE TESTING OF VALVE TRAIN COMPONENTS




CHRYSLER 2.2L ENGINE
ROLLER FOLLOWER
WITH STEEL
ROLLER
WITH CERAMIC
ROLLER
NEEDLE BEARINGS
STEEL ROLLER
CERAMIC ROLLER

SUMMARY

- SPECIALIZED, TECHNOLOGY-INTENSIVE, HIGH-VALUE-ADDED ADVANCED CERAMICS ARE MOVING TOWARD COMMERCIALIZATION TO FILL THE DEMAND FOR LIGHTER, STRONGER, MORE CORROSION RESISTANT MATERIALS
- ADVANCEMENTS WILL RELY MORE AND MORE ON PROCESSING AND MODELING FROM THE ATOMIC SCALE UP WHICH IS MADE POSSIBLE BY ADVANCED ANALYTIC, COMPUTER, AND PROCESSING TECHNIQUES
- SPECIALIZED PROPERTIES AND HIGHER COST WILL PROVIDE BOTH NEW OPPORTUNITIES AND CHALLENGES TO DESIGNERS AND END-USERS
    - MORE RIGOROUS DEFINITION OF COMPONENT REQUIREMENTS
    - COMPONENT REDESIGN TO ACCOMMODATE BRITTLE BEHAVIOR
    - SYSTEM REDESIGN TO MAKE FULL USE OF NEW MATERIALS
    - CLOSER COUPLING BETWEEN DESIGNERS AND MATERIALS DEVELOPERS